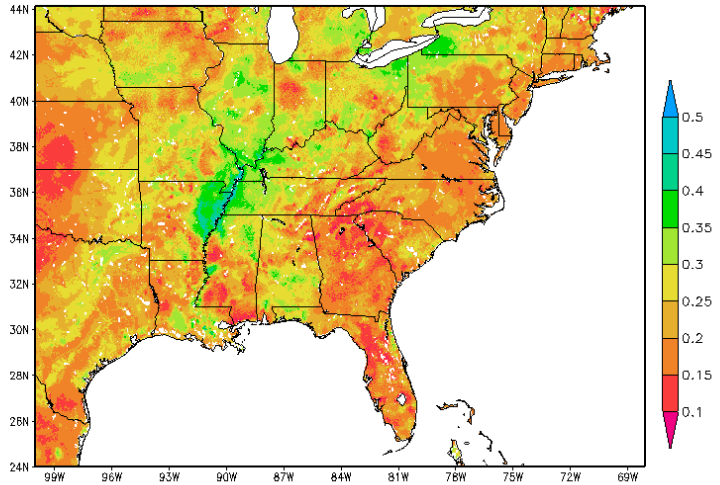
SMAP Soil Moisture Retrieval Assimilation for Improved Weather Forecasting



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Jonathan Case *(ENSCO, Inc.)*

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Christopher Hain *(NASA-MSFC)*

Bradley Zavodsky *(NASA-MSFC)*

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Overview of Project

Assimilate SMAP L2 retrievals of soil moisture (9km Enhanced) into the Noah LSM within the Land Information System

- *Data assimilation via Ensemble Kalman Filter*
- *Baseline is existing SPoRT LIS run in CONUS and East Africa*
- *Builds on experience assimilating SMOS*
- *Assess impact of SMAP on soil moisture*

Initialize NWP Forecasts with SPoRT LIS and SMAP LIS

- *Investigate impact of SMAP DA on NWP forecasts*
- *Case studies and statistical verification*

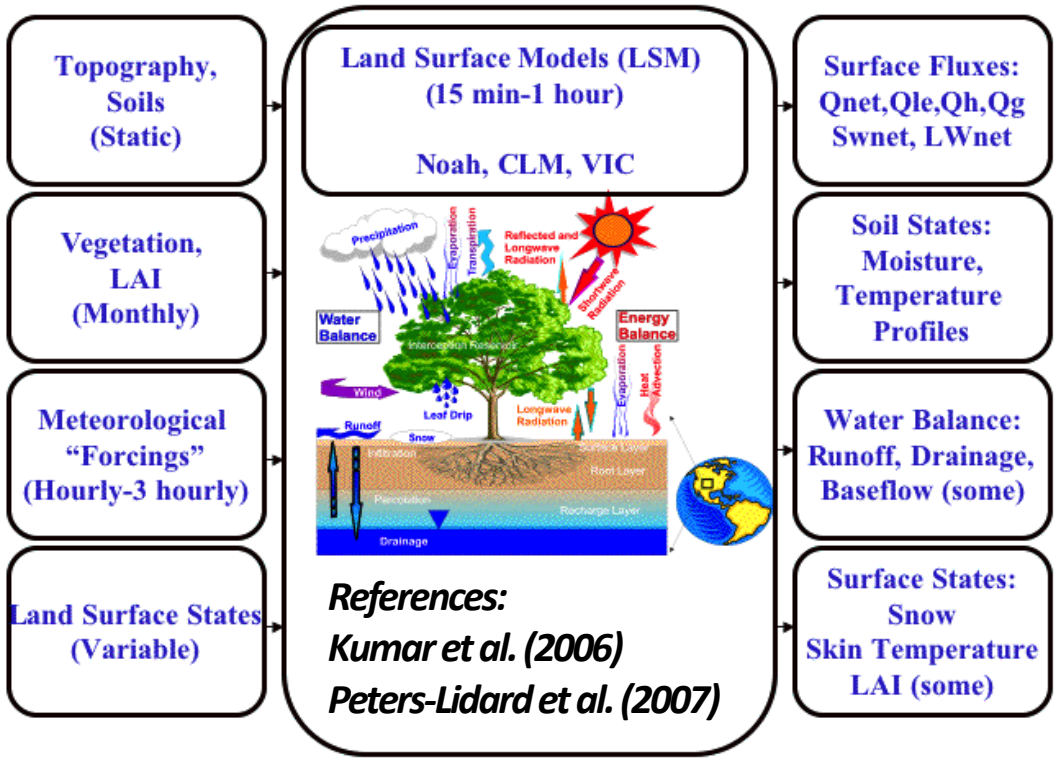
Goals and Progress

Domain	CONUS	East Africa
Assimilate SMAP in LIS Implementation Refinement Validation (vs. station measurements)	 ✓ In progress ✓(initial)	 ✓ In progress
Coupled NU-WRF Experiments (LIS+WRF) Case studies Validation (48-h weather forecasts)	 In progress	

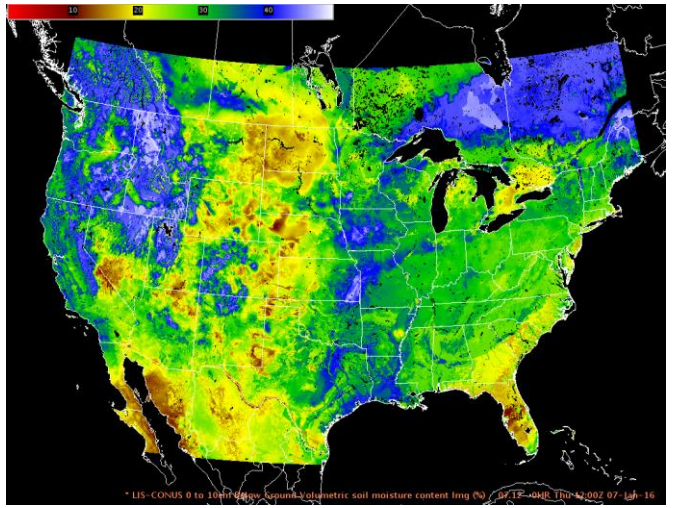
Refinement of methodology

- Vertical layers
- Bias correction methods (soil type, pointwise, hybrid)
- Ensemble size, perturbations, weighting

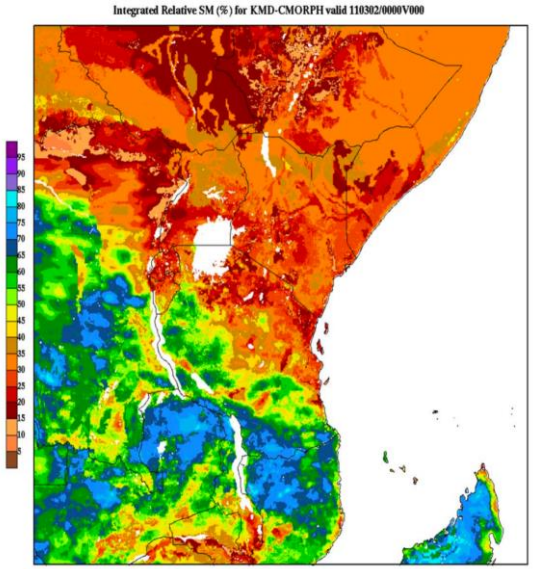
Land Information System (LIS)



References:
Kumar et al. (2006)
Peters-Lidard et al. (2007)



SPoRT-LIS total column soil moisture displayed in AWIPS II



East Africa LIS domain

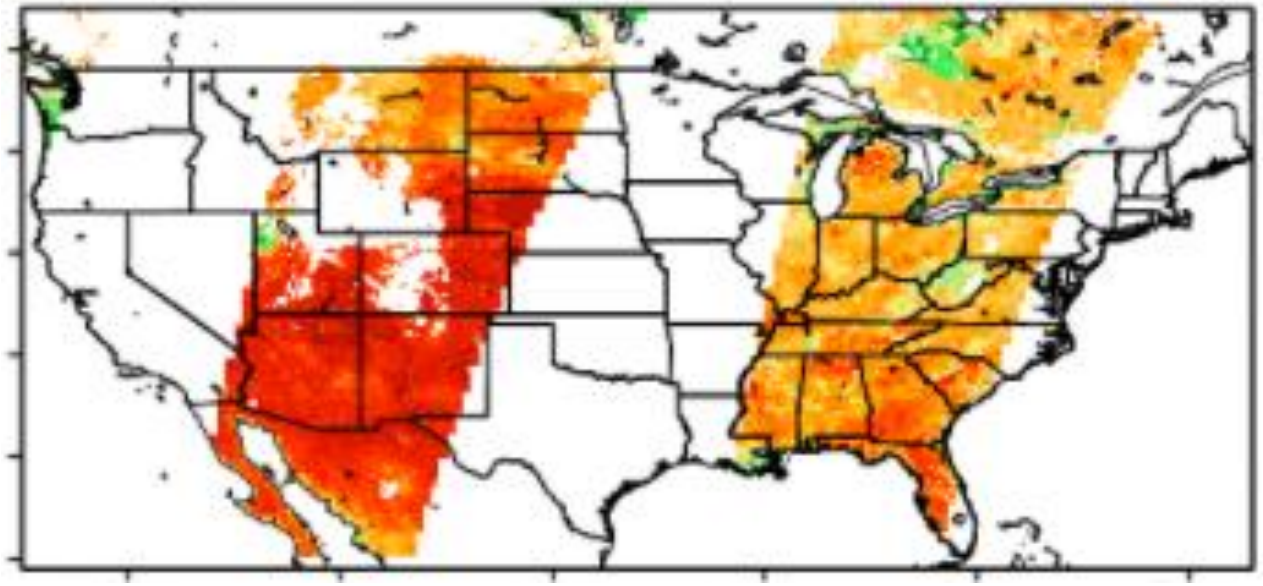
- Framework for running LSMs incorporating a wide variety of meteorological forcing data and land surface parameters
  - Developed by NASA-GSFC
  - Includes data assimilation capability.
  - Can be run coupled with Advanced Research WRF.
- Using Noah 3.3 Land Surface Model (LSM) within LIS
- SPoRT maintains near-real-time and experimental LIS runs
  - SE US (3-km), shared with WFO's
  - East Africa, shared with Kenya Meteorological Service (KMS)

SMAP L2 Assimilation in SPoRT LIS

Customized LIS to add SMAP L2 soil moisture retrievals
(half-orbit files)
Using 9-km “Enhanced” product
3-km CONUS domain based on ongoing SPoRT-LIS run

12 ensemble members
1 month ensemble spinup

SMAP observation applied at multiple grid cells
Custom soil-type-based non-localized
CDF-matching
(testing other approaches)
Evaluating impact of SMAP



SMAP Surface Soil Moisture
(Observations Assimilated into LIS)

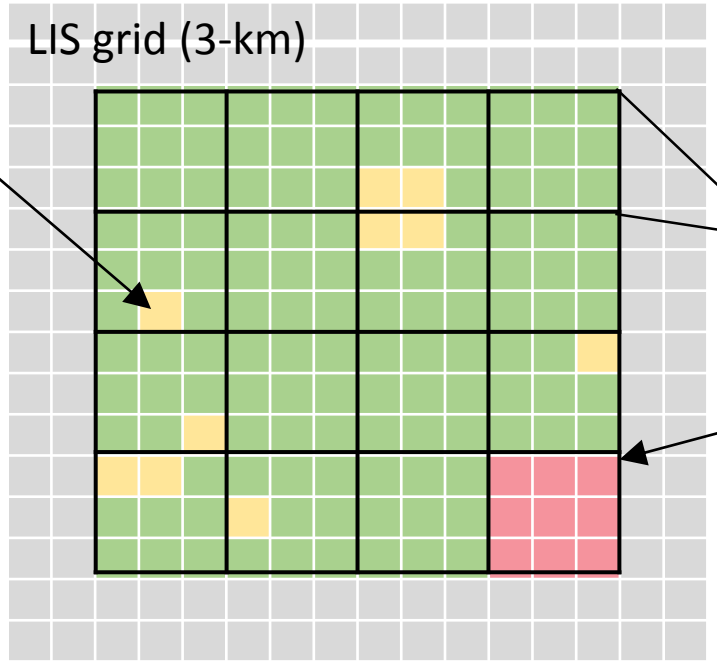
Observation mapping and QC

- Level 2 data are available on 9-km EASE grid
- To take advantage of high resolution geophysical properties (topography, vegetation, soils), running model at 3-km
- SMAP observations are assimilated at each model grid point in their FOV
- Downscaling to preserve background variability implemented

Model-based QC applied on LIS grid

- Precip (changed to 1 mm/hr)
- Frozen ground
- Snow on ground
- GVF>0.7
- Extreme values

Bias correction is applied on LIS grid.



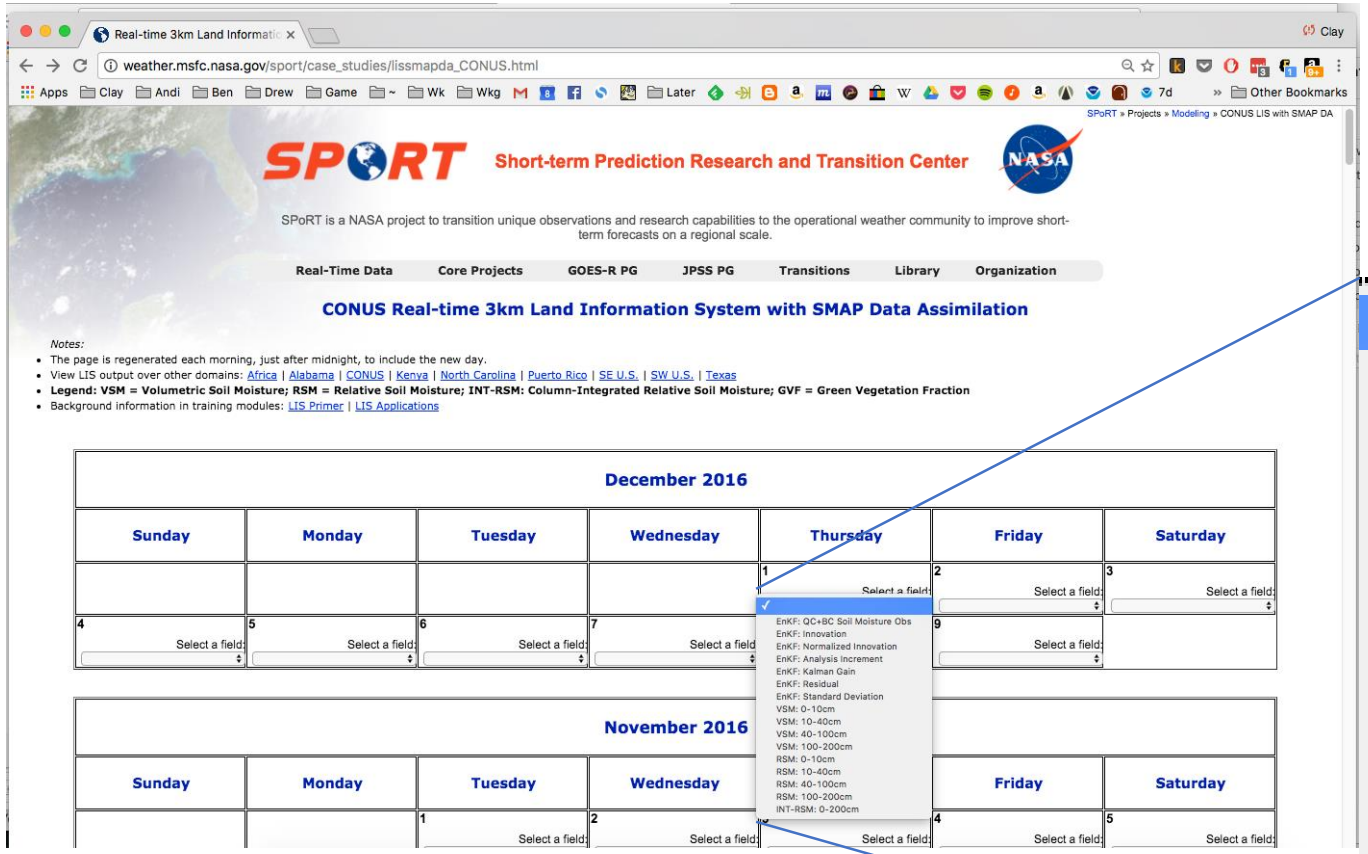
SMAP enhanced (passive) 9-km cell

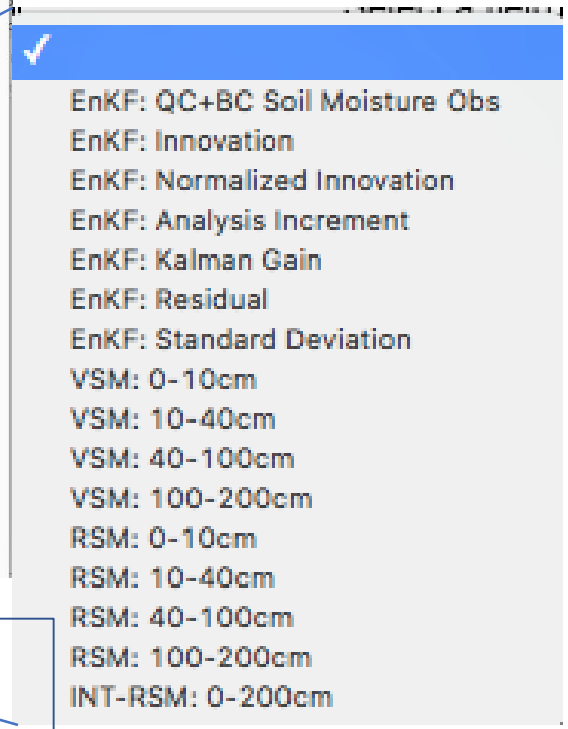
Observation-based QC at 9-km resolution

- RFI
- Retrieval Quality Flag
- Vegetation Water Content
- Frozen Ground Fraction

(In reality, SMAP and LIS grids are not aligned.)

SPoRT LIS Web Interface





https://weather.msfc.nasa.gov/sport

->Realtime Data

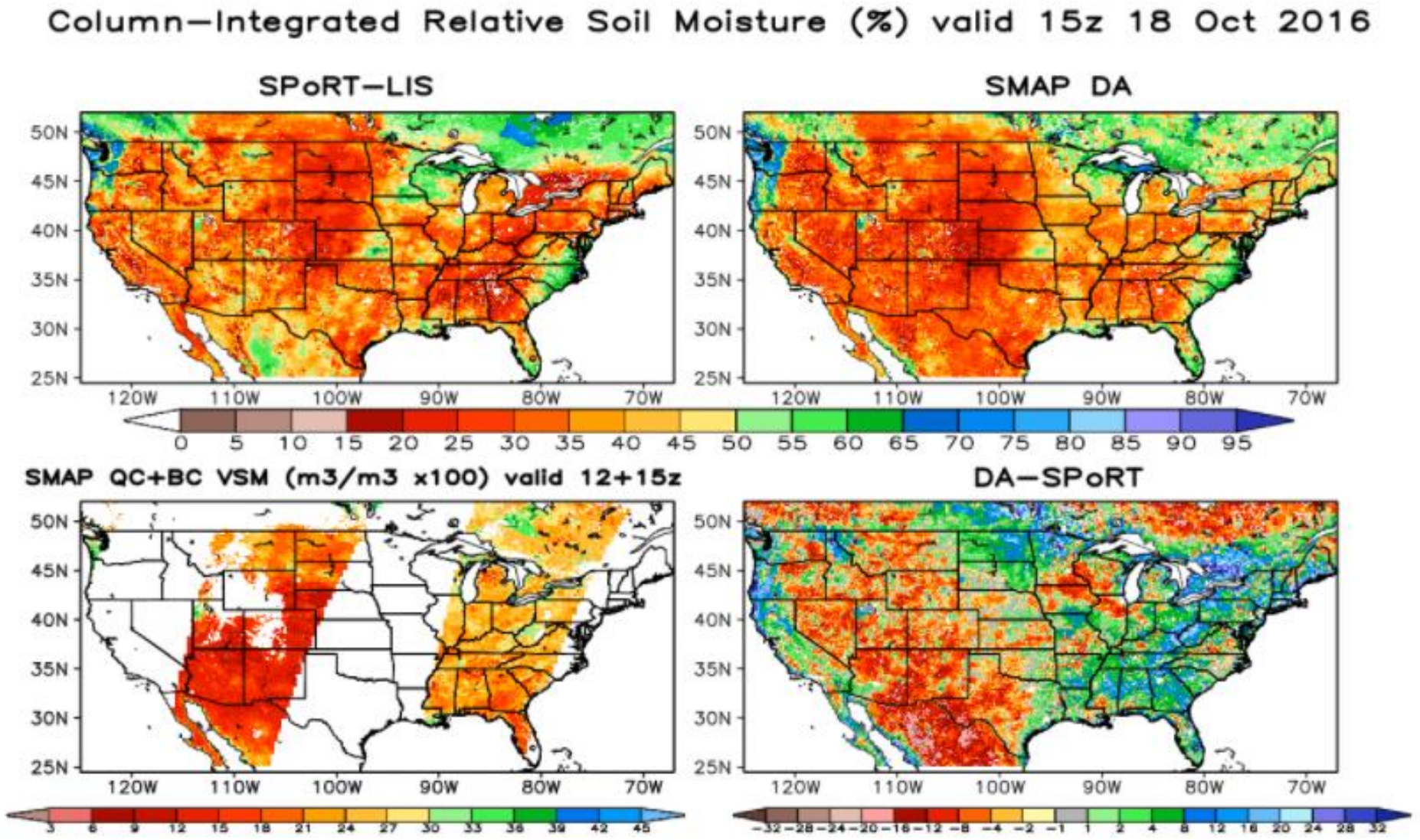
->SMAP Soil Moisture

->Realtime Data

->Land Information System

->SPoRT LIS + SMAP DA

LIS Web Products from SPoRT: SMAP LIS



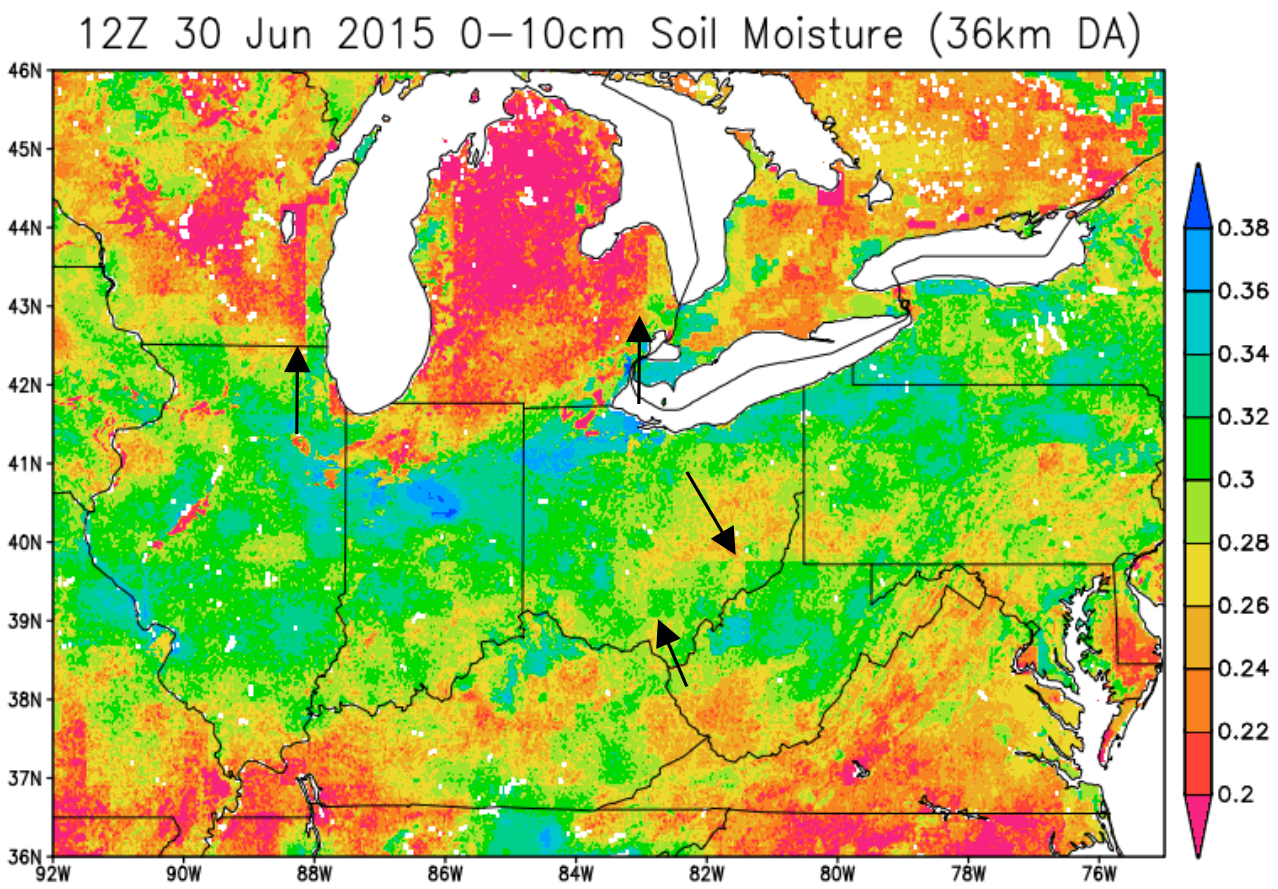
- 0-10 cm model soil moisture

https://weather.msfc.nasa.gov/sport/case_studies/lissmapda_CONUS.html

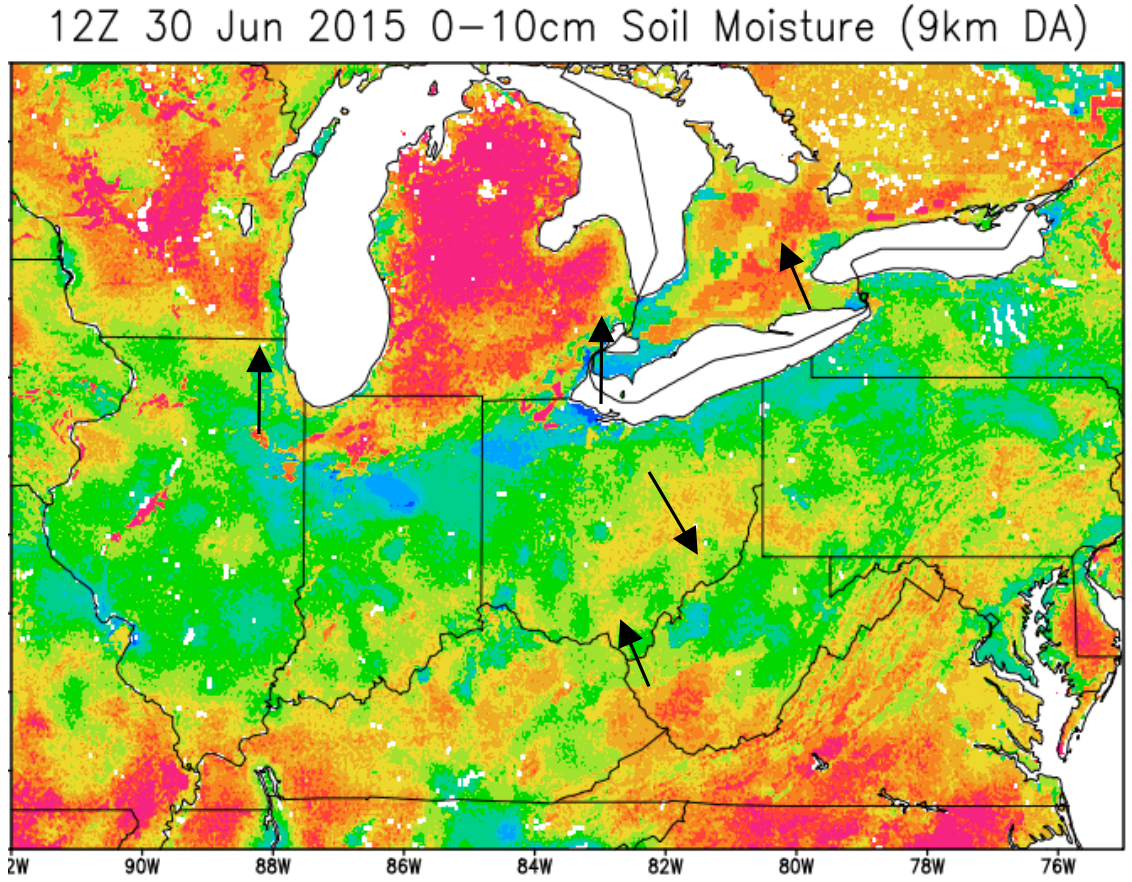
Assimilation of SMAP Enhanced (9-km) Product

0-10 cm Volumetric Soil Moisture (%)

LIS with 36-km SMAP DA

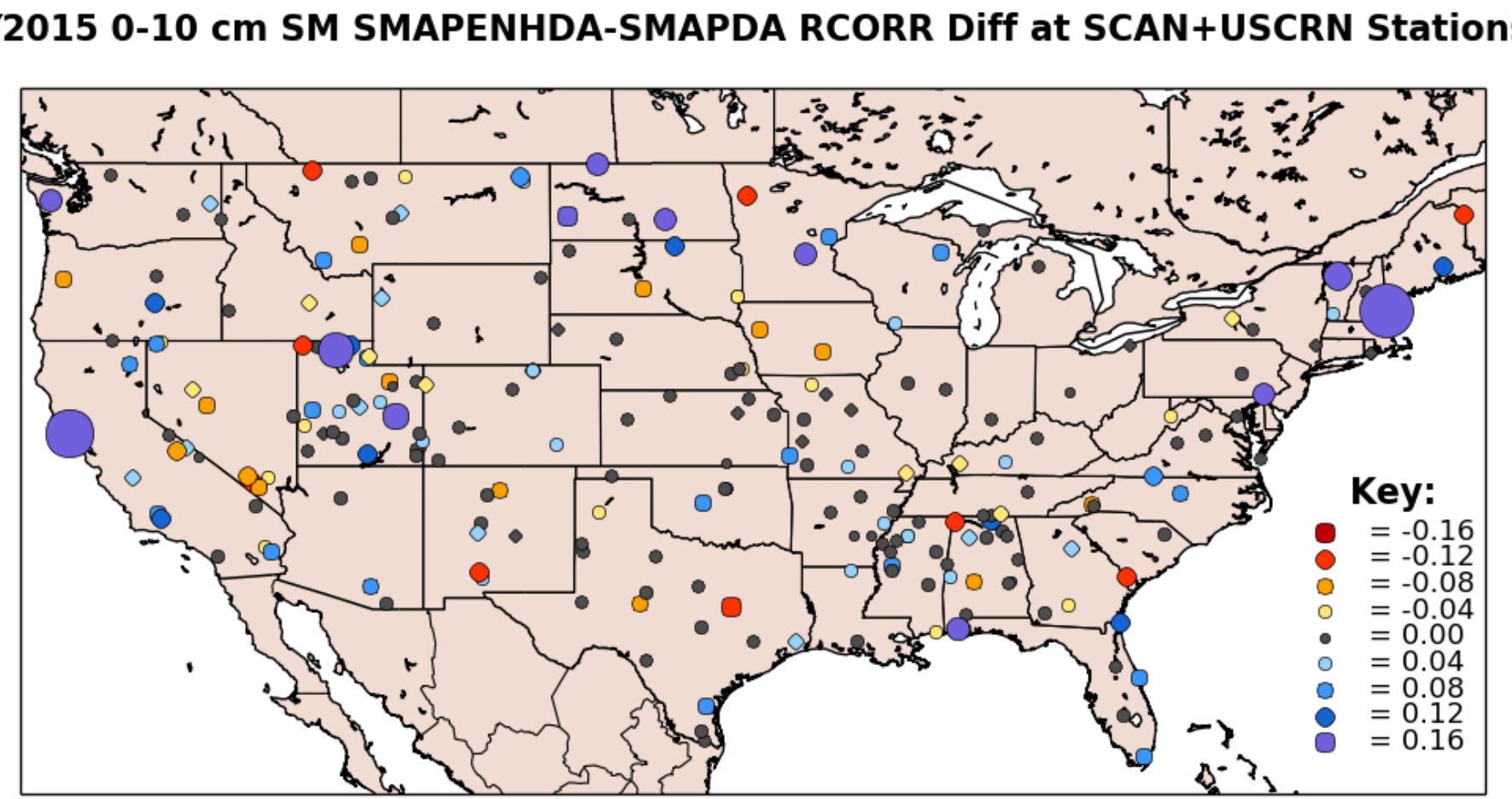


LIS with 9-km SMAP DA



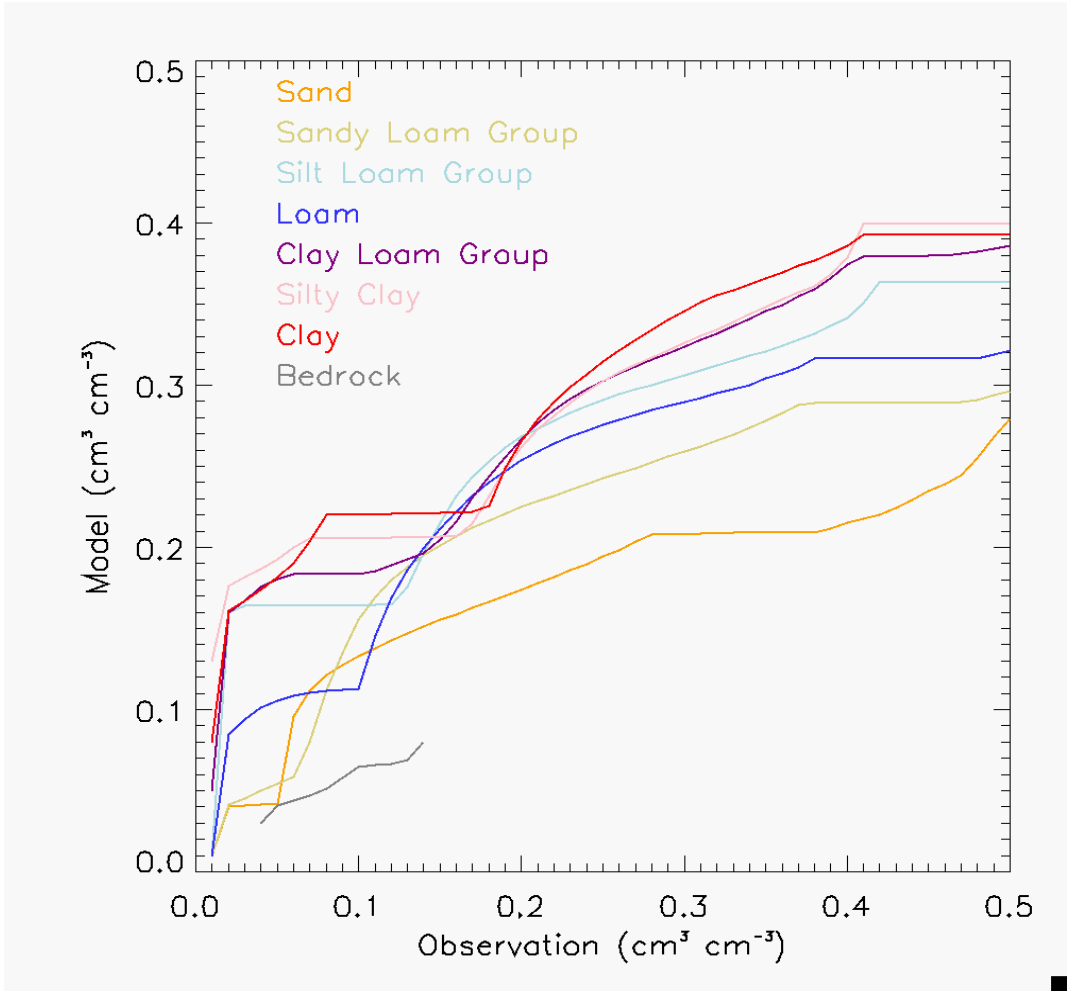
Note linear and square features (e.g., at arrows) on left resulting from the coarse 36-km resolution of the SMAP data. Reduced on right due to using 9-km Enhanced SMAP data.

Impact of Enhanced SMAP (correlations)



Bias Correction

- Assimilation systems assume unbiased observations
- LIS can apply point-by-point correction curves. Many implementations generate climatologies of model and obs at each grid point.
- We have implemented CDF matching aggregated by soil type
  - Described for SMOS in Blankenship et al. 2016 (*IEEE TGRS*)
  - Idea is to let the observations influence the model climatology
- Other methods being explored
  - Point=-by-point
  - Hybrid (matching soiltype in neighborhood)
- Using a thinner soil moisture layer may reduce forward operator error and subsequently the magnitude of bias corrections



Correction Curves By Soil Type

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SMAP Assimilation Reduces Errors due to Poor QC in Forcing Data

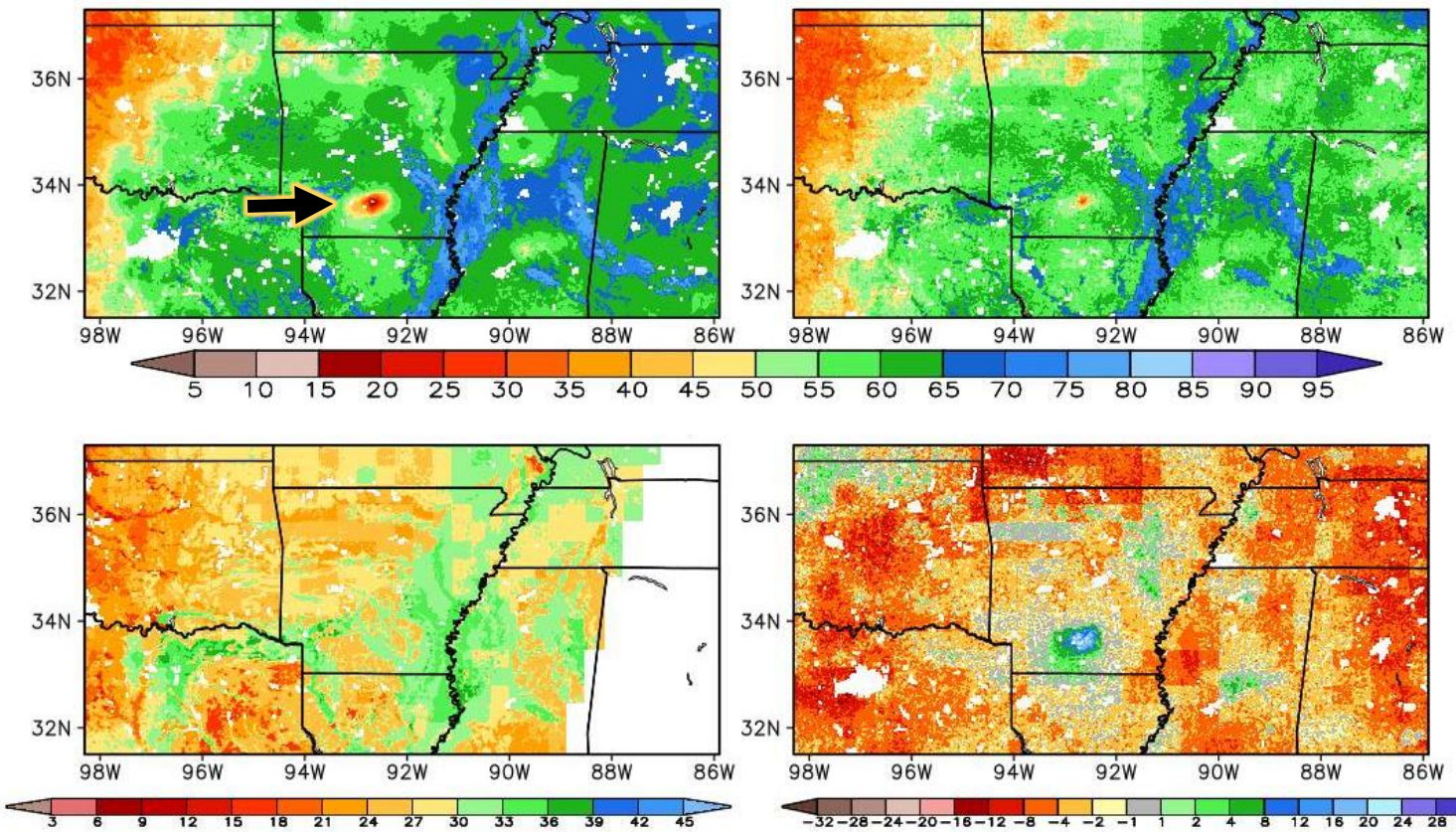
- Land surface models such as SPoRT LIS are forced using precipitation inputs (NLDAS-2 in this case)
- In 2015, NLDAS-2 included data from a bad rain gauge (consistently near zero) in southern Arkansas causing an anomalously dry soil moisture “bullseye” (upper left, arrow).
- Through assimilation of SMAP L2 soil moisture fields, which do not exhibit this feature (lower left), this anomaly is greatly reduced over time (upper right) to provide a more representative soil moisture field.
  - Snapshot is 24 days after beginning of assimilation.
- This results in a more accurate depiction of local conditions.

0-2 m Column Integrated Relative Soil Moisture (%)

12Z 24 Apr 2015

Baseline SPoRT LIS

SPoRT LIS with SMAP DA



SMAP Retrieved Soil Moisture

0-5 cm, volumetric (m^3/m^3 x100)

Non-localized CDF-matching bias correction applied

LIS Difference

(SMAP DA Minus Baseline SPoRT)

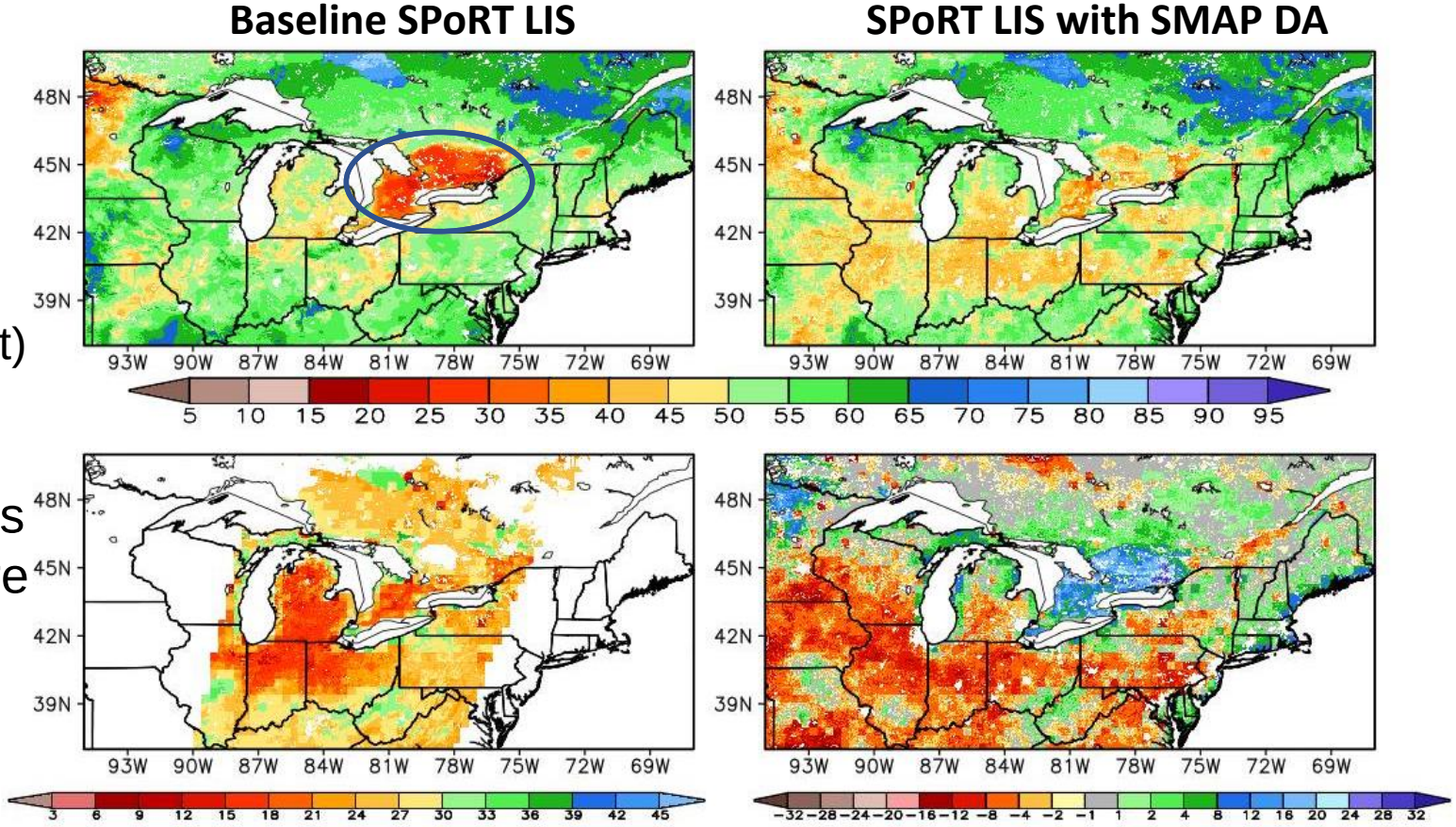
Column Integrated RSM (%)

Credit: Youlong Xia, Pingping Xie (NCEP/EMC); David Mocko (NASA/GSFC)

Better Blending of Soil Moisture Across US-Canada Border

- Soil moisture discontinuities can occur in regions where different precipitation inputs are blended
  - NLDAS-2 uses radar-derived precipitation over U.S. and reanalysis outside of U.S.
  - Results in anomalous dry conditions in southern Ontario (upper left, oval)
  - SMAP retrieved soil moisture (lower left) does not have this feature.
- Through assimilation of SMAP L2 soil moisture fields, this anomaly disappears over time (upper right) to provide a more representative soil moisture field
- This should help forecasters better assess current regional conditions and provide more accurate initialization of NWP models.

0-2 m Column Integrated Relative Soil Moisture (%)
12Z 4 Jun 2016

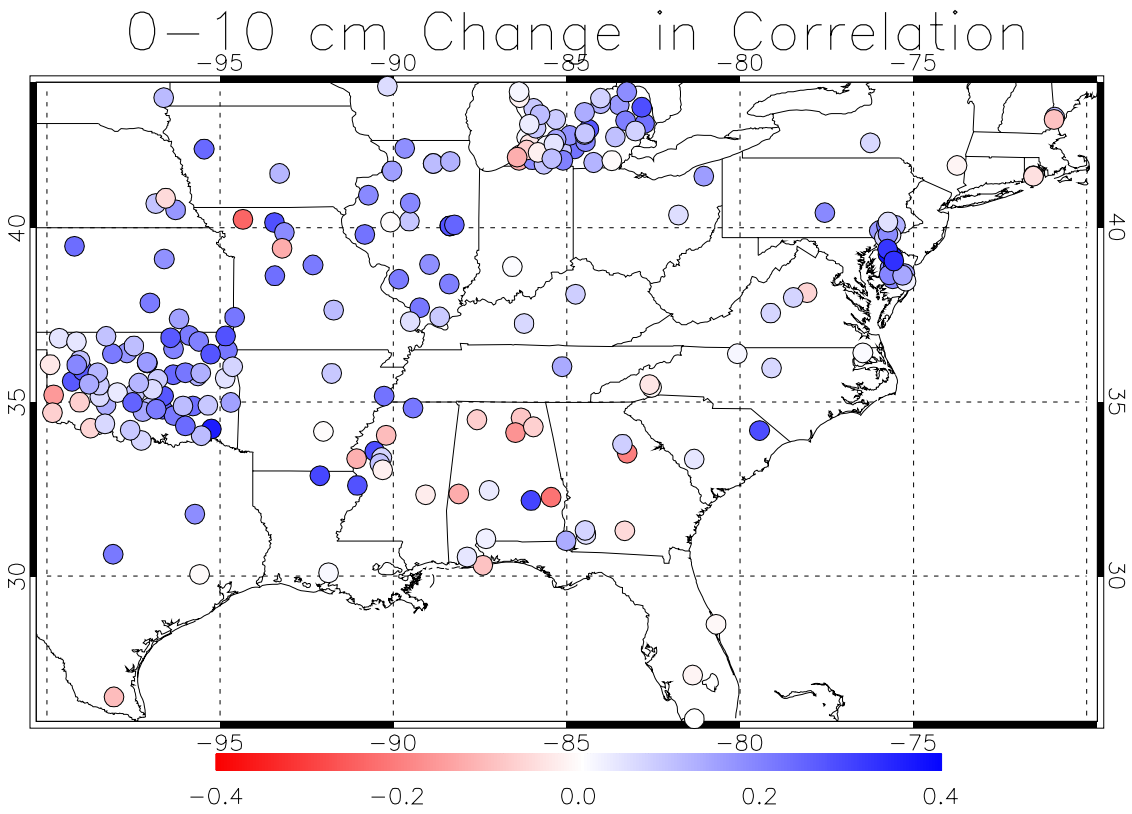


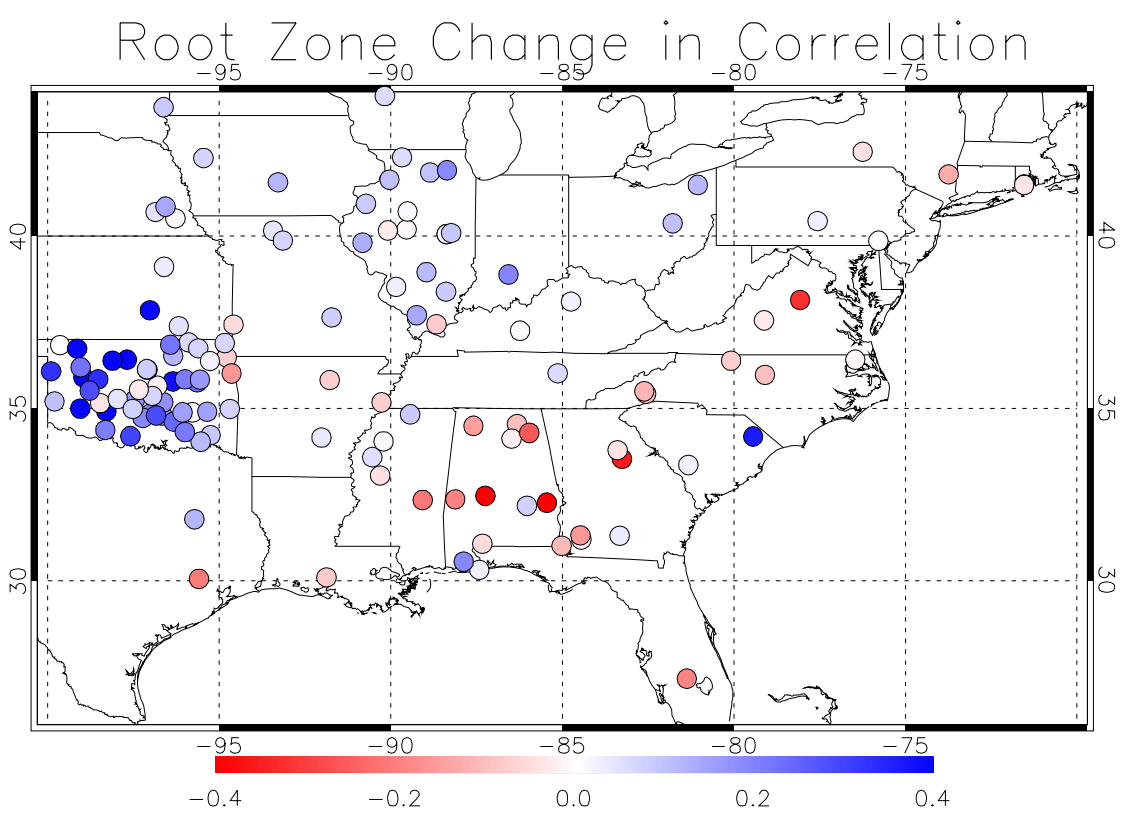
SMAP Retrieved Soil Moisture
0-5 cm, volumetric (m^3/m^3 x100)
Non-localized CDF-matching bias correction applied

LIS Difference
(SMAP DA Minus Baseline SPoRT)
Column Integrated RSM (%)

Credit: Youlong Xia, Pingping Xie (NCEP/EMC); David Mocko (NASA/GSFC)

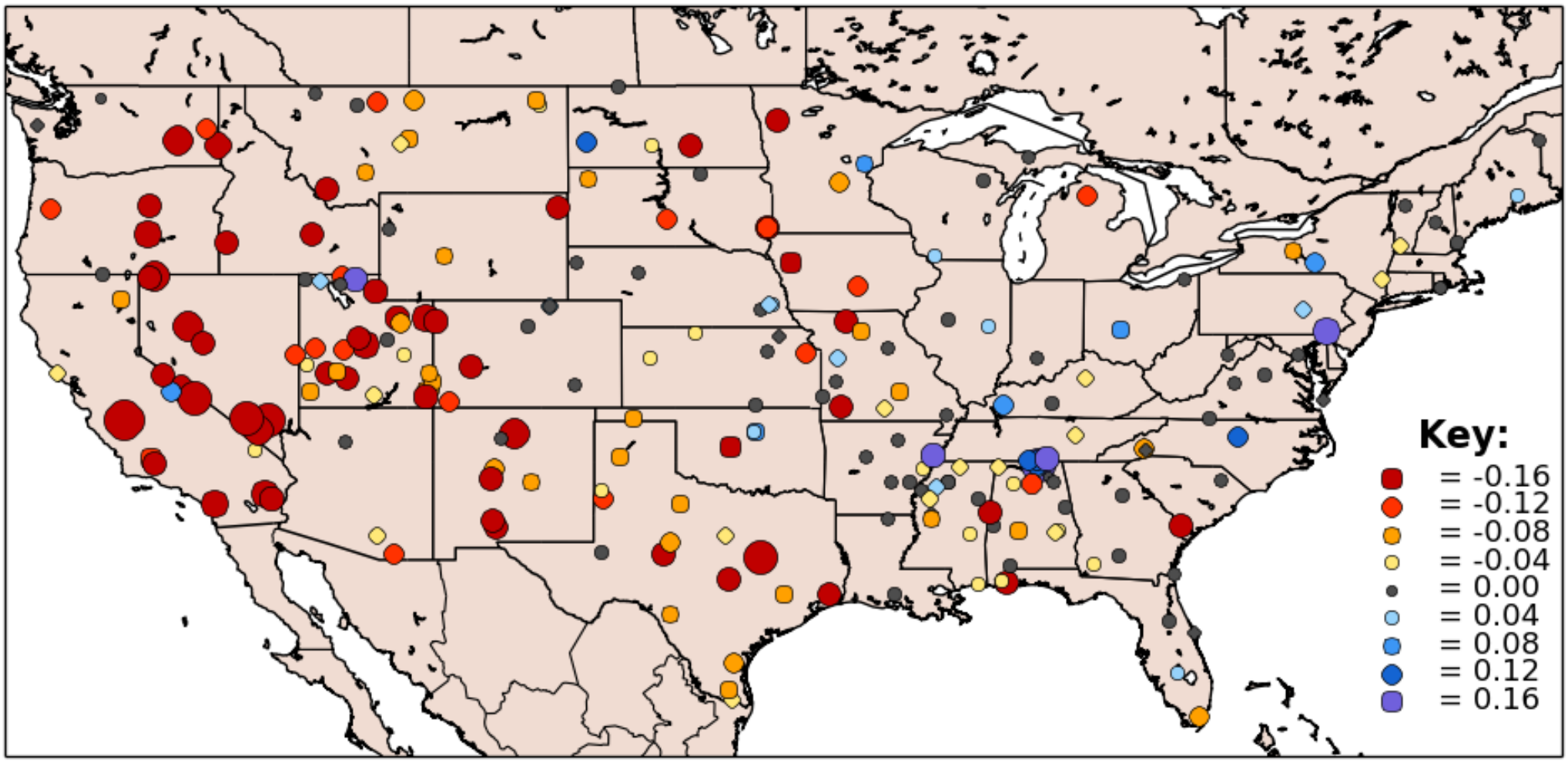
Previous Validation Results (SMOS DA)



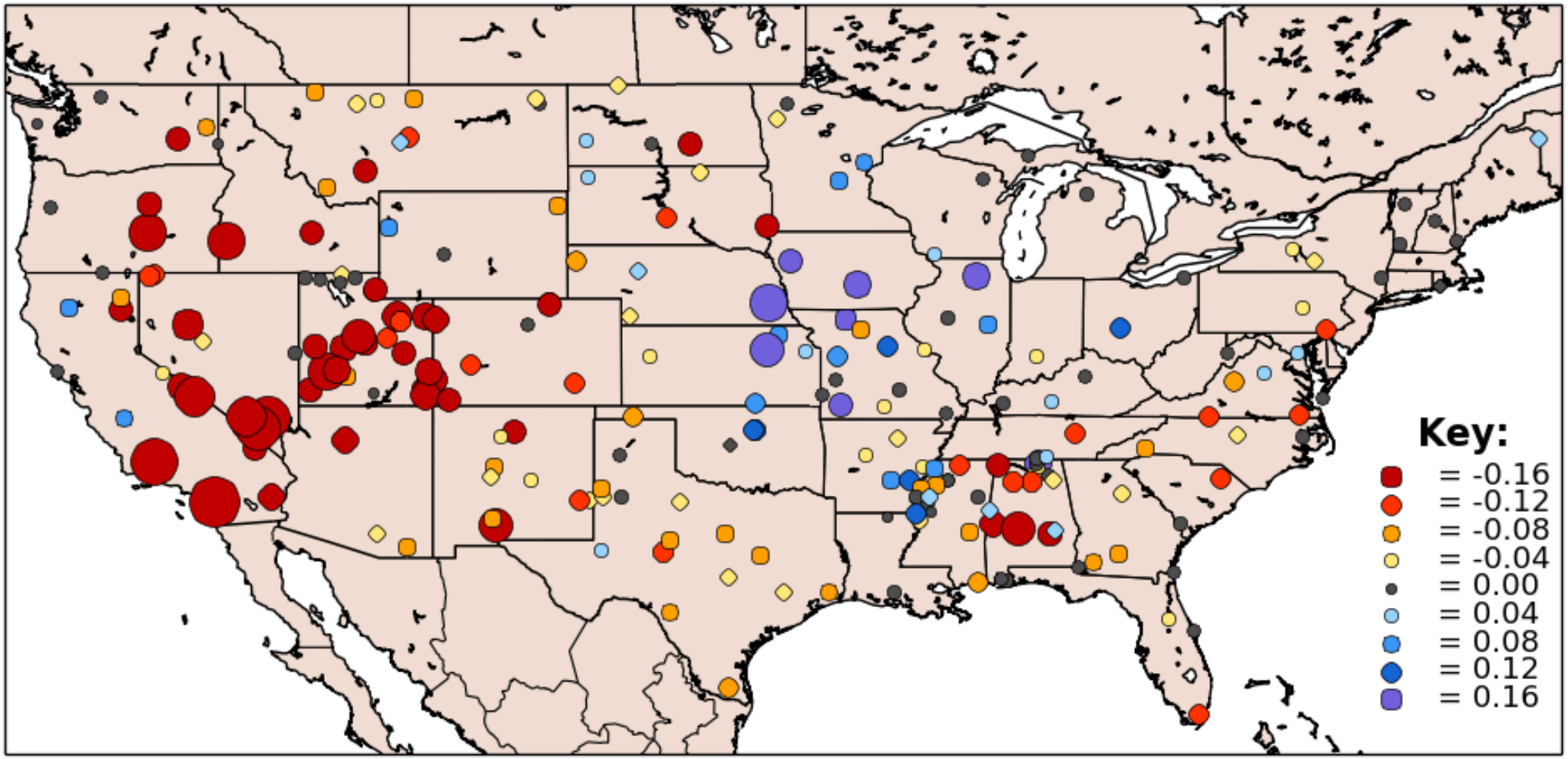


	Near Surface (0-10 cm)			Root Zone (10-100 cm)		
	Bias	Err SD	**Corr.**	Bias	Err SD	**Corr.**
Control	3.6%	23.5%	**0.47**	4.0%	10.6%	**0.61**
SMOS DA	-0.5%	21.8%	**0.57**	10.6%	11.8%	**0.67**

SMAP Correlation change 2015

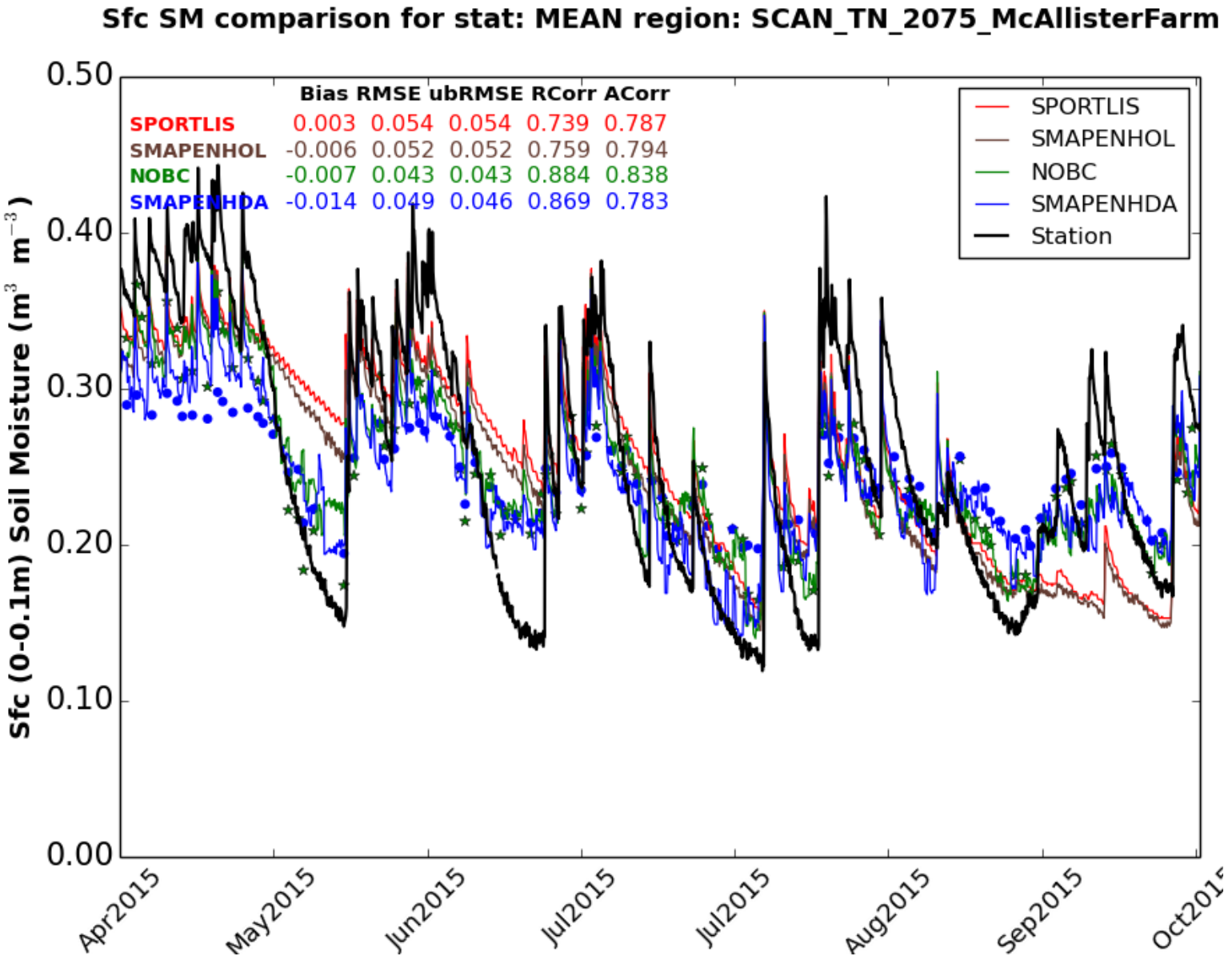


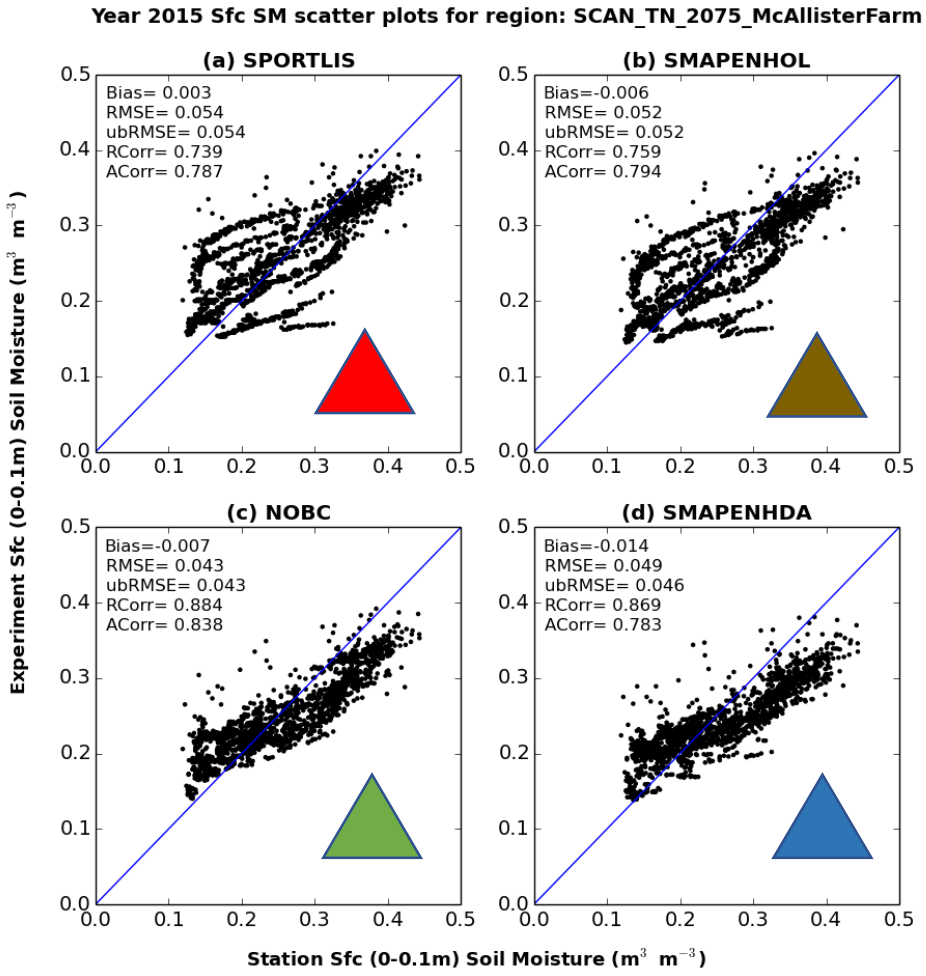
SMAP Correlation change 2016



New Validation Results (SMAP DA)

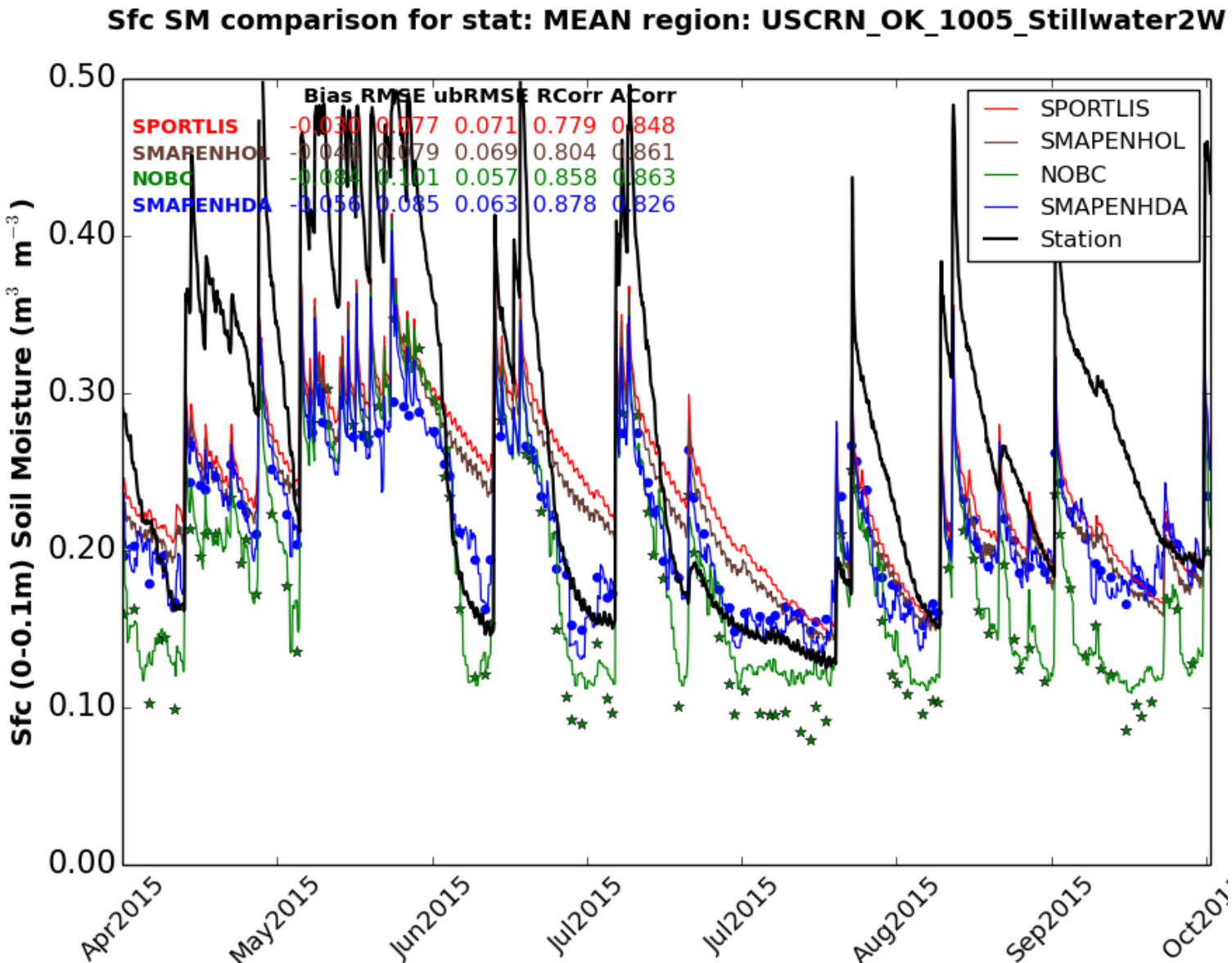
- Corr increases from .79 to .84 (NOBC)
- ubRMSE decreases from .054 to .043

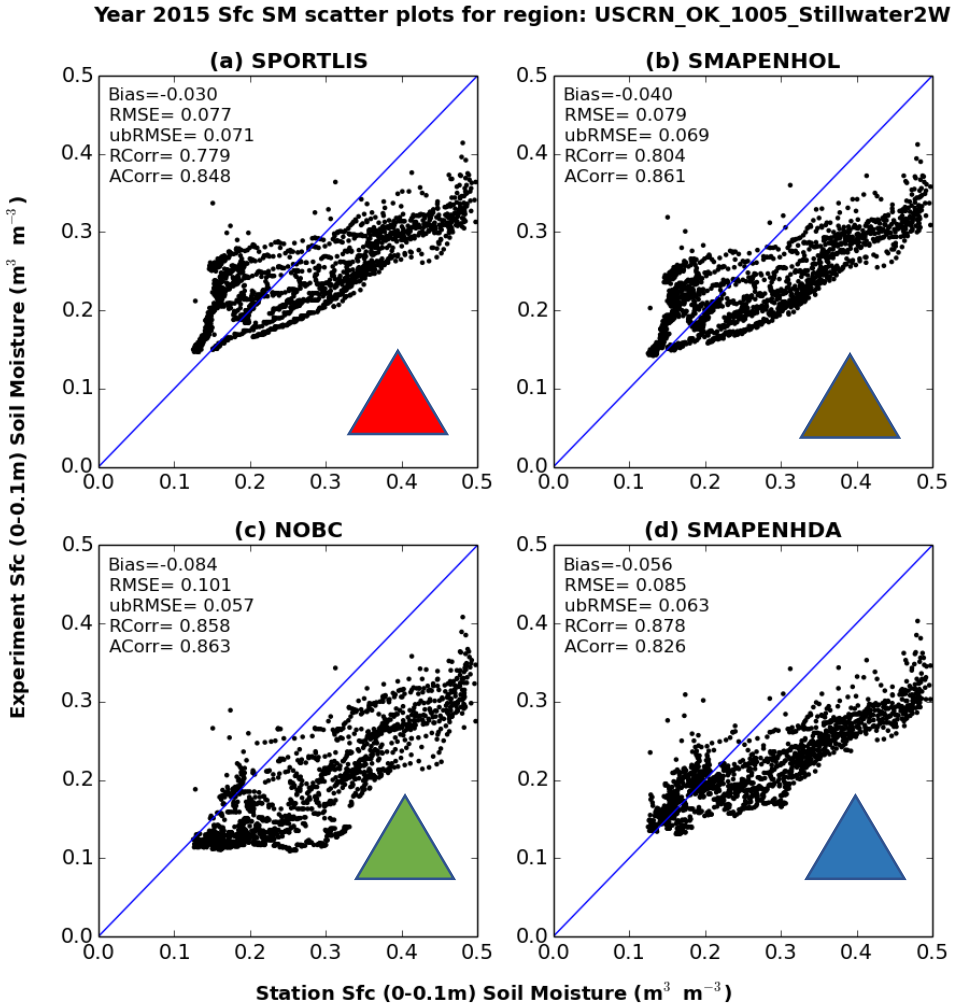




New Validation Results (SMAP DA)

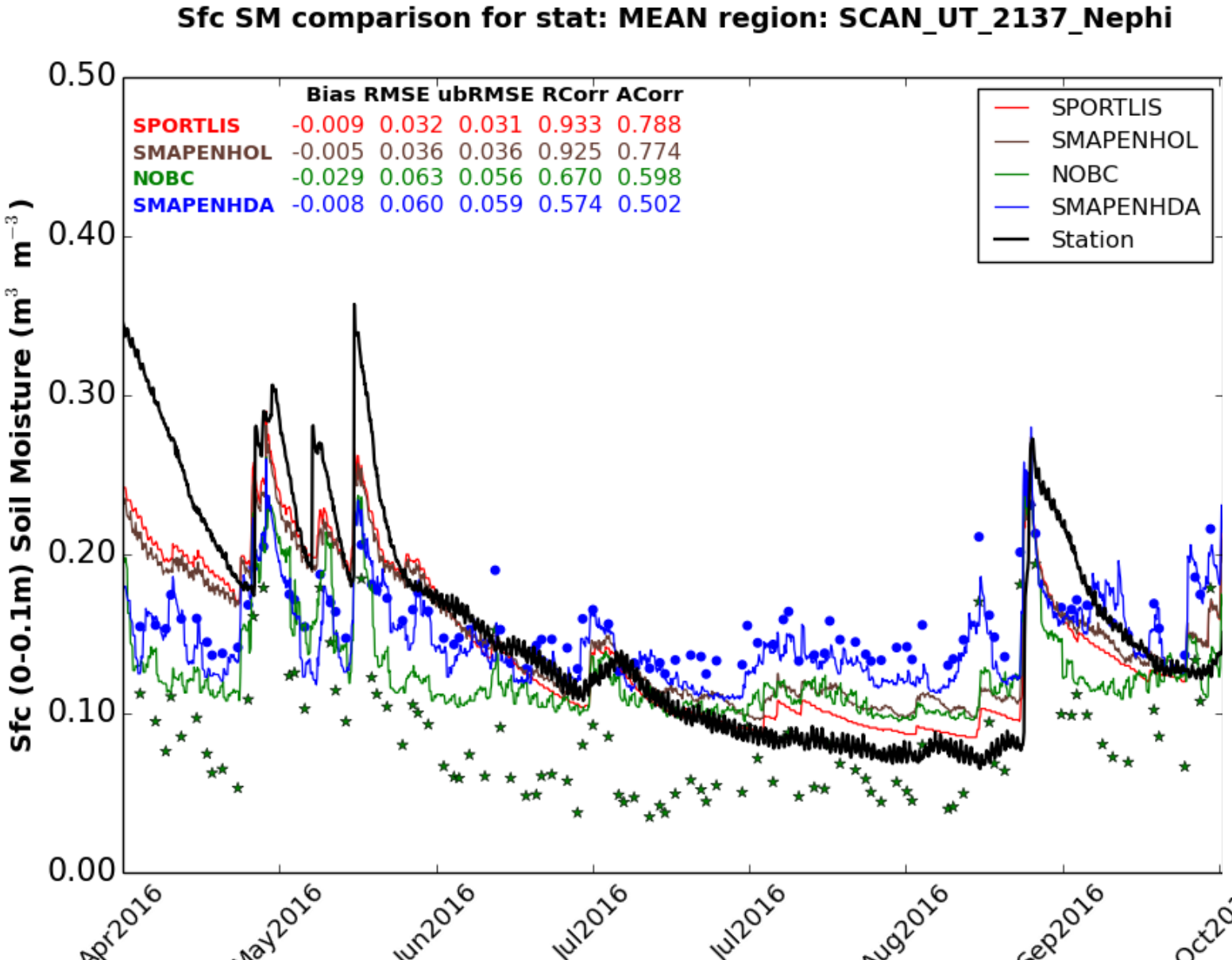
- Corr increases from .78 to 85 (NOBC)
- ubRMSE decreases from .071 to .057

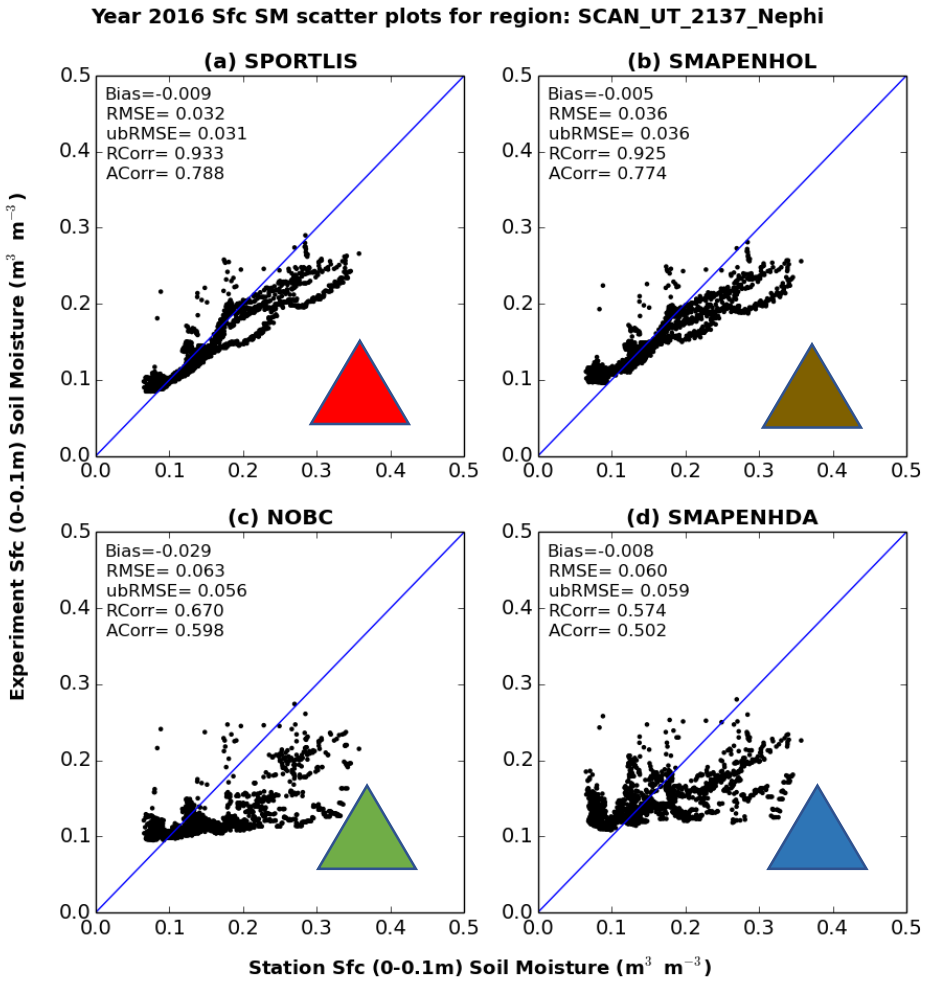




New Validation Results (SMAP DA)

- Corr decreases from .93 to .67 (NOBC)
- ubRMSE increases from .031 to .059

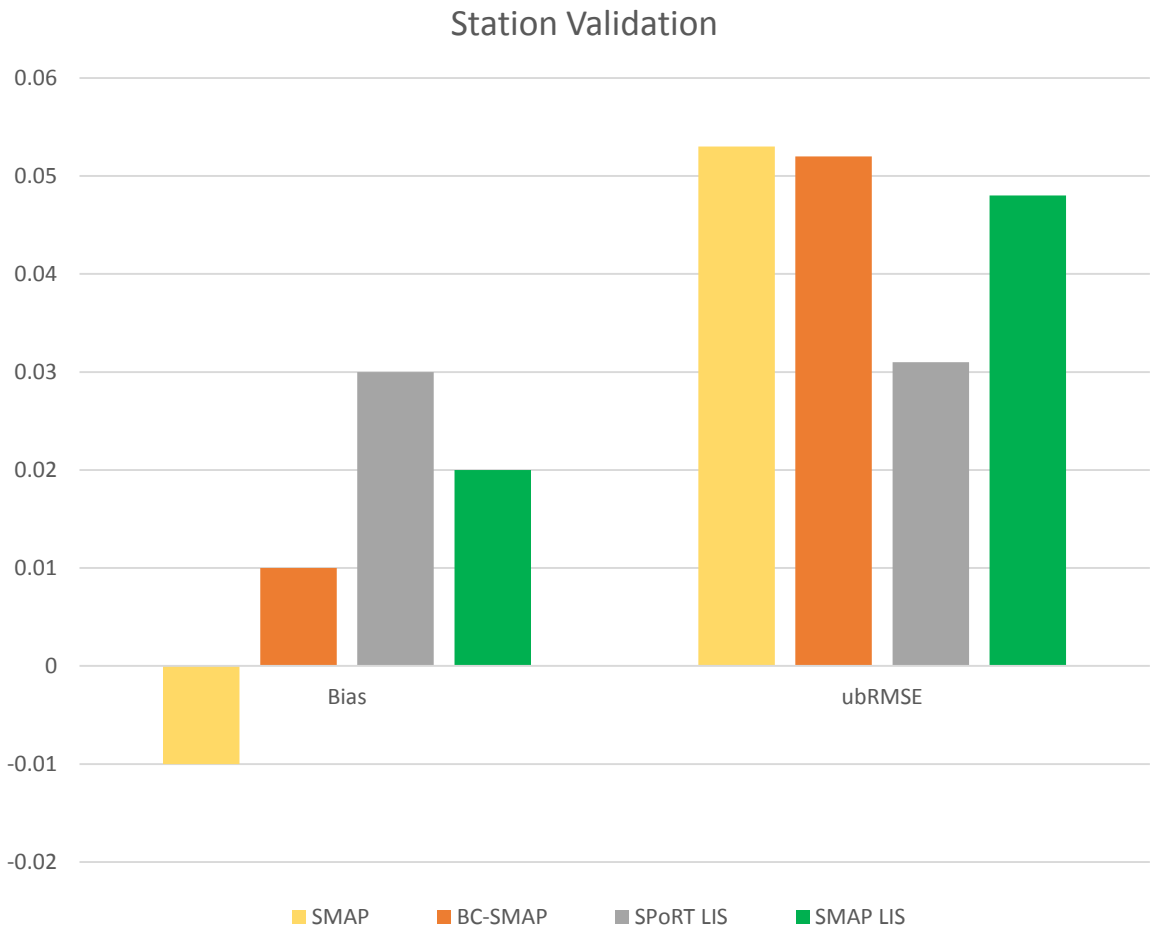


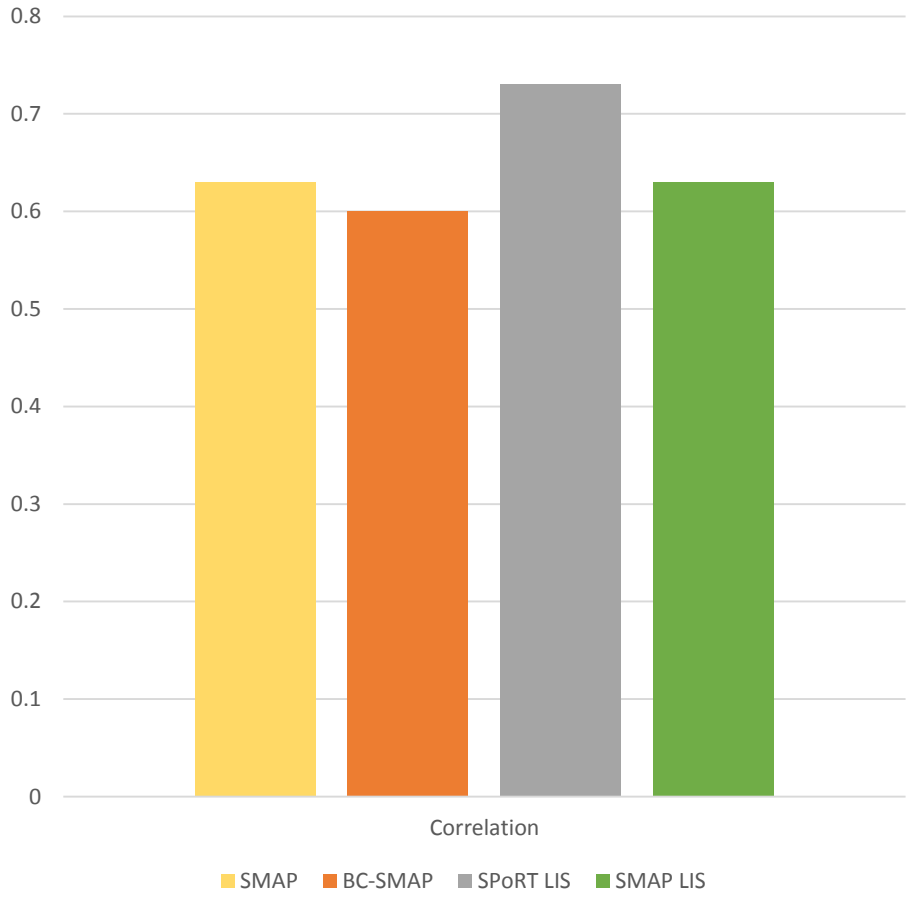


Possible Issues (and findings)

- Bias Correction
  - NoBC run indicates BC has a minor effect on statistics
- AM/PM data
  - Validation of retrievals indicates small difference
- Representativeness (point vs grid cell, also vertical) of validation data
  - Previously got positive impact (correlations) with SMOS
  - Others getting good impact
- Depth discrepancies
  - (10 cm model layer, 5 cm or less SMAP measurement)
  - Experiment in progress
  - Previously got positive impact with SMOS
- Information content of 3-km LSM is too hard to match with 9-km obs
  - Previously got positive impact with SMOS

Quantitative Validation Results





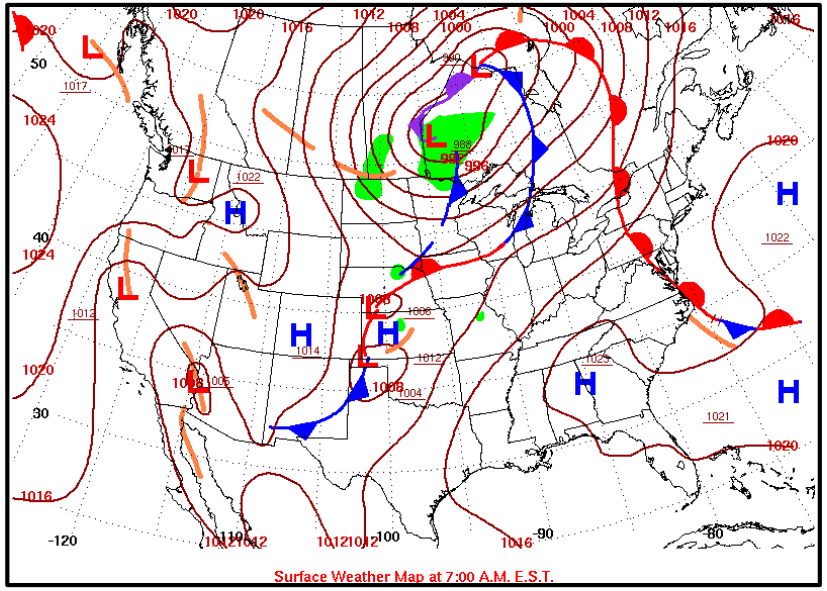
NWP Initialization Results

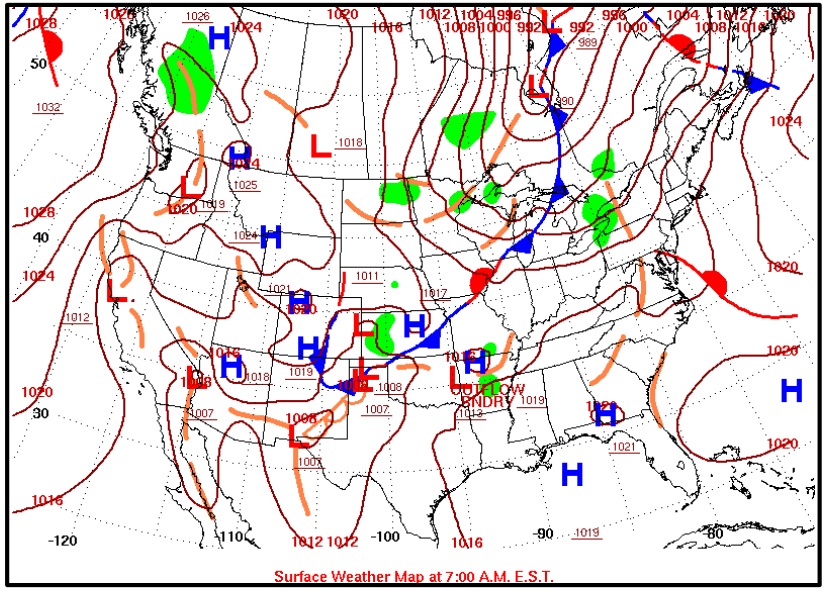
WRF case over NEUS

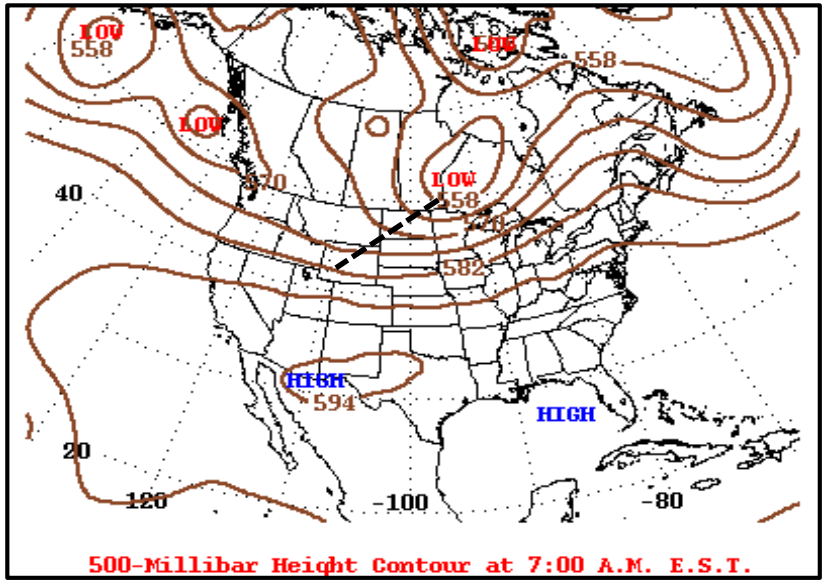
SPoRT-LIS vs. SMAP-Enh DA initialized runs

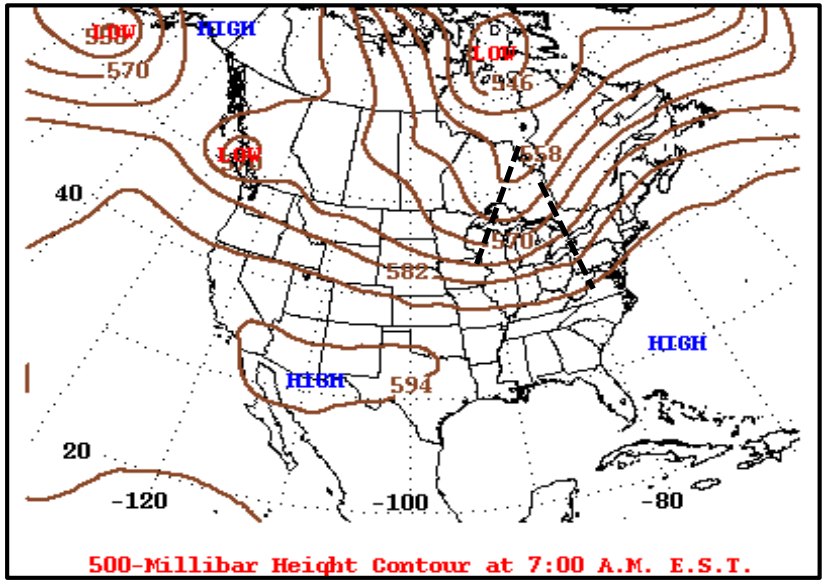
[13-14 July 2016 severe squall line event]

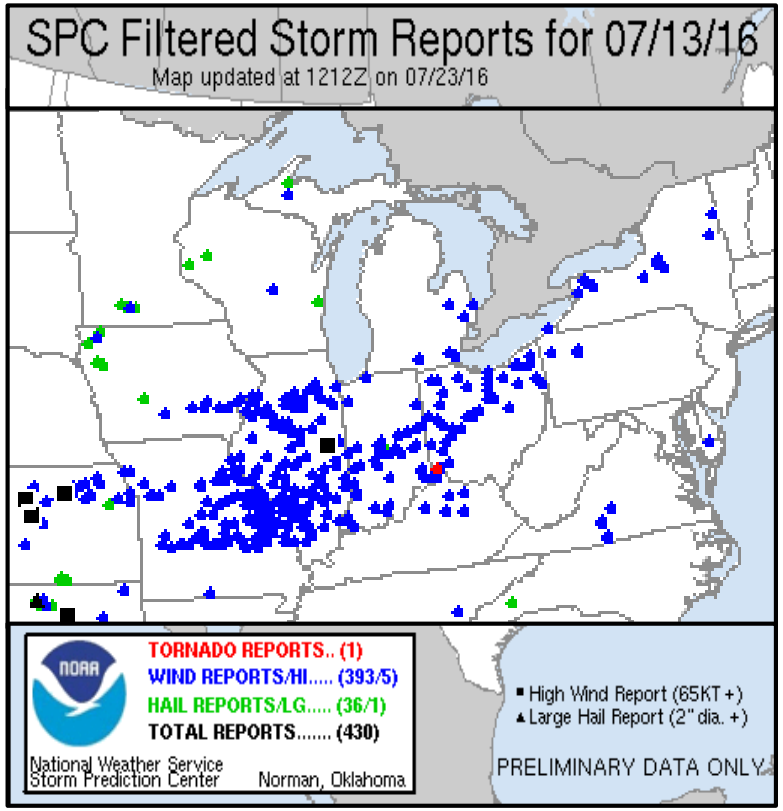
13-14 July 2016 severe squall line





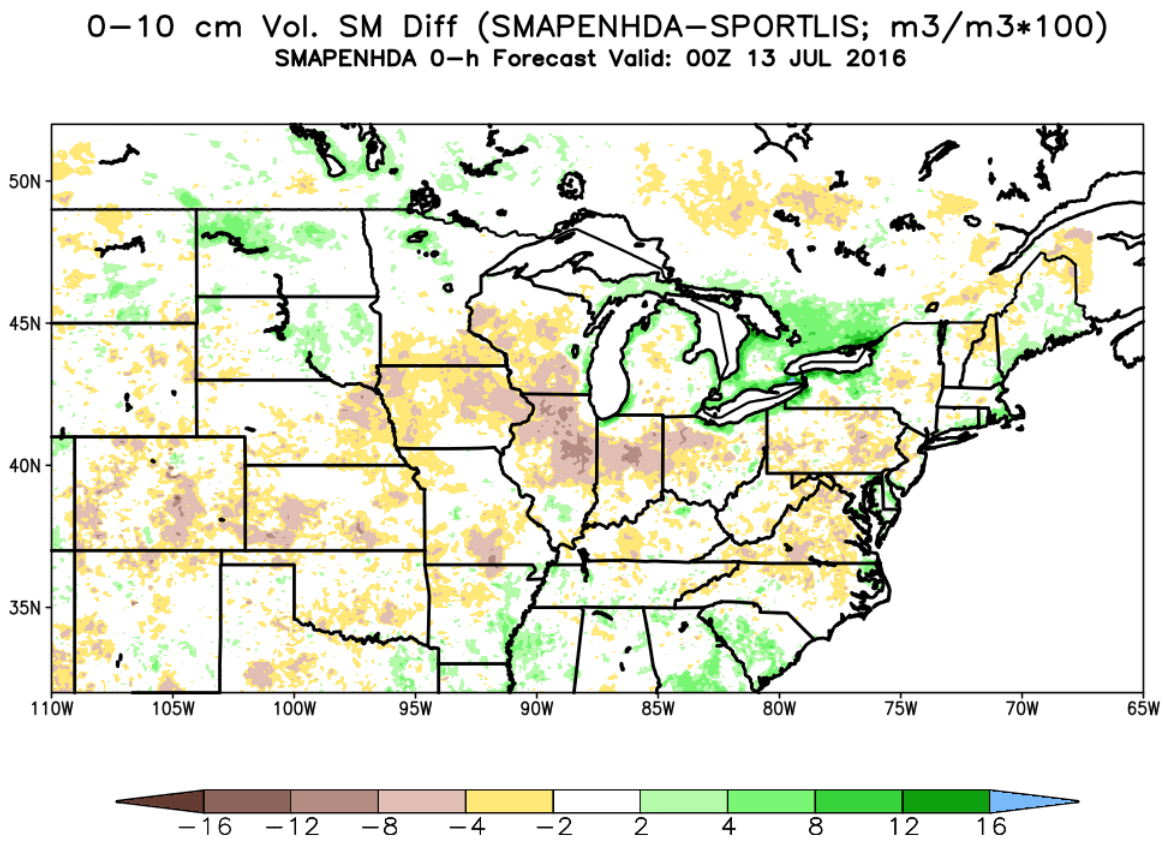


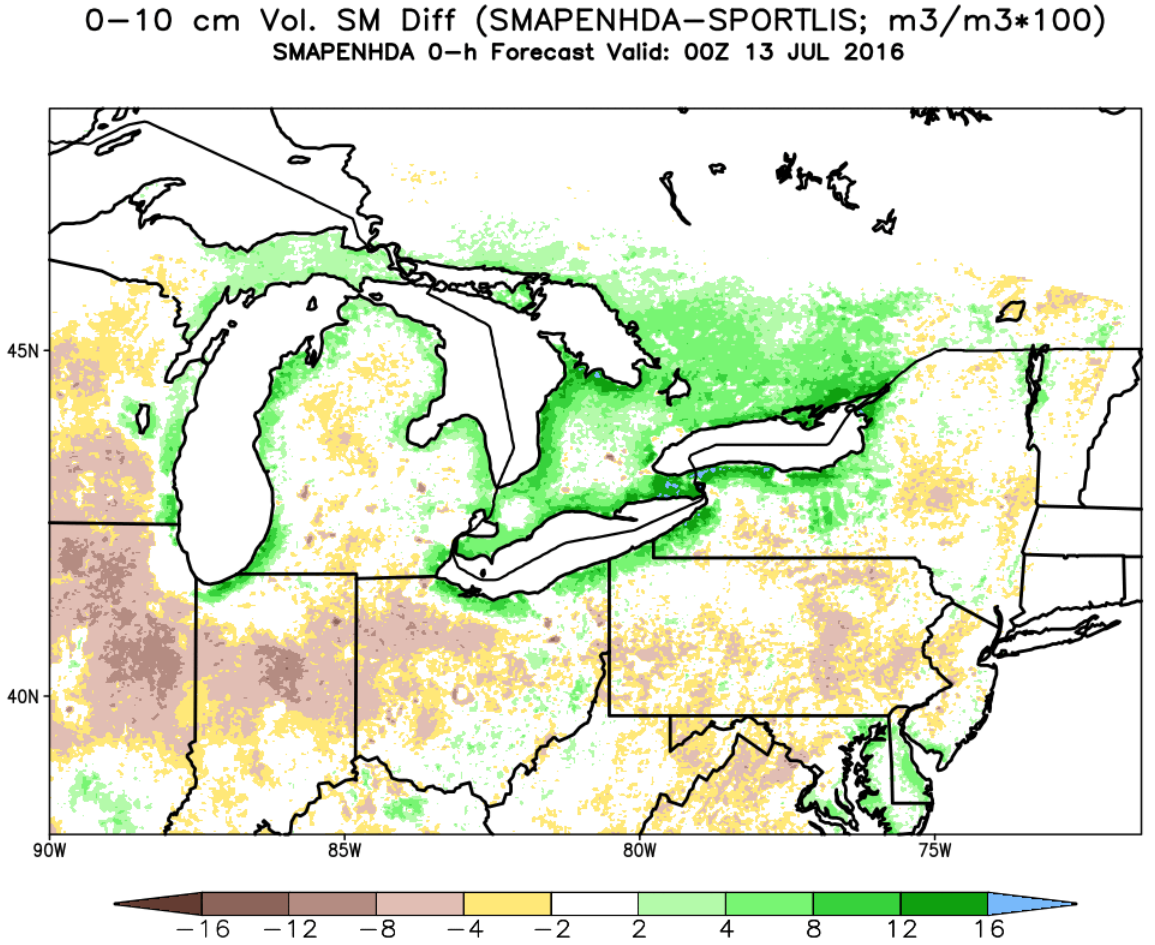




00z 13 July Soil Moisture Initialization Differences:

0-10 cm volumetric soil moisture

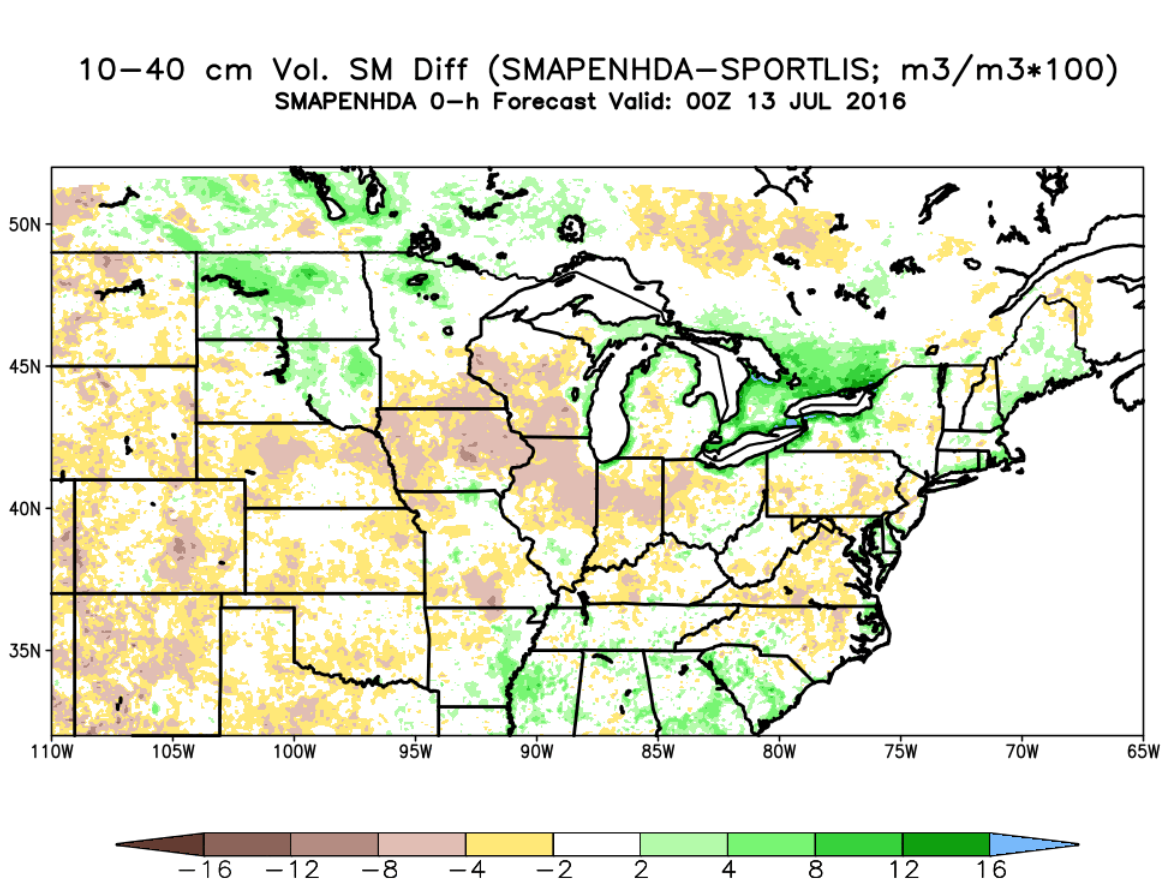


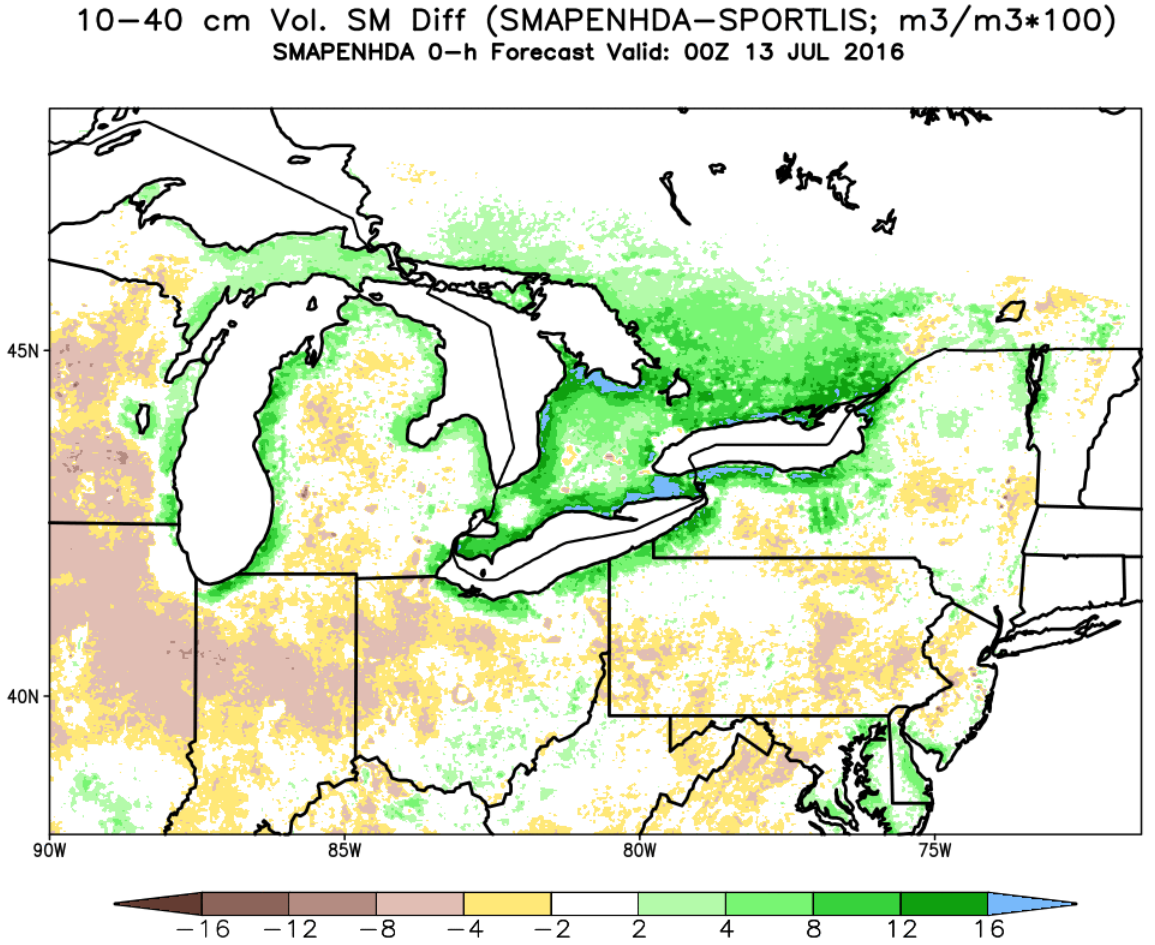


- Drier signal in Midwest/Cornbelt;
- More moist in SE Canada (corrected dry artifact in SPoRT-LIS soils)

00z 13 July Soil Moisture Initialization Differences:

10-40 cm volumetric soil moisture

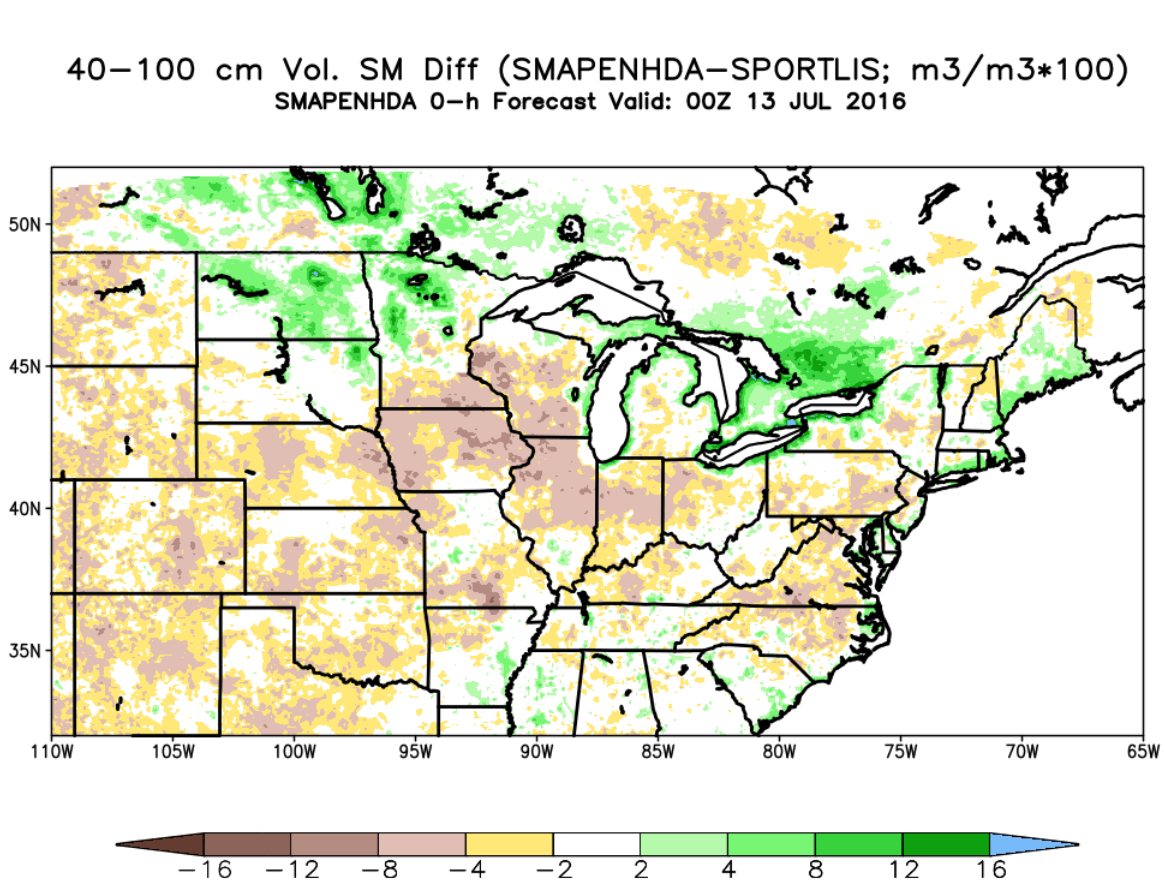


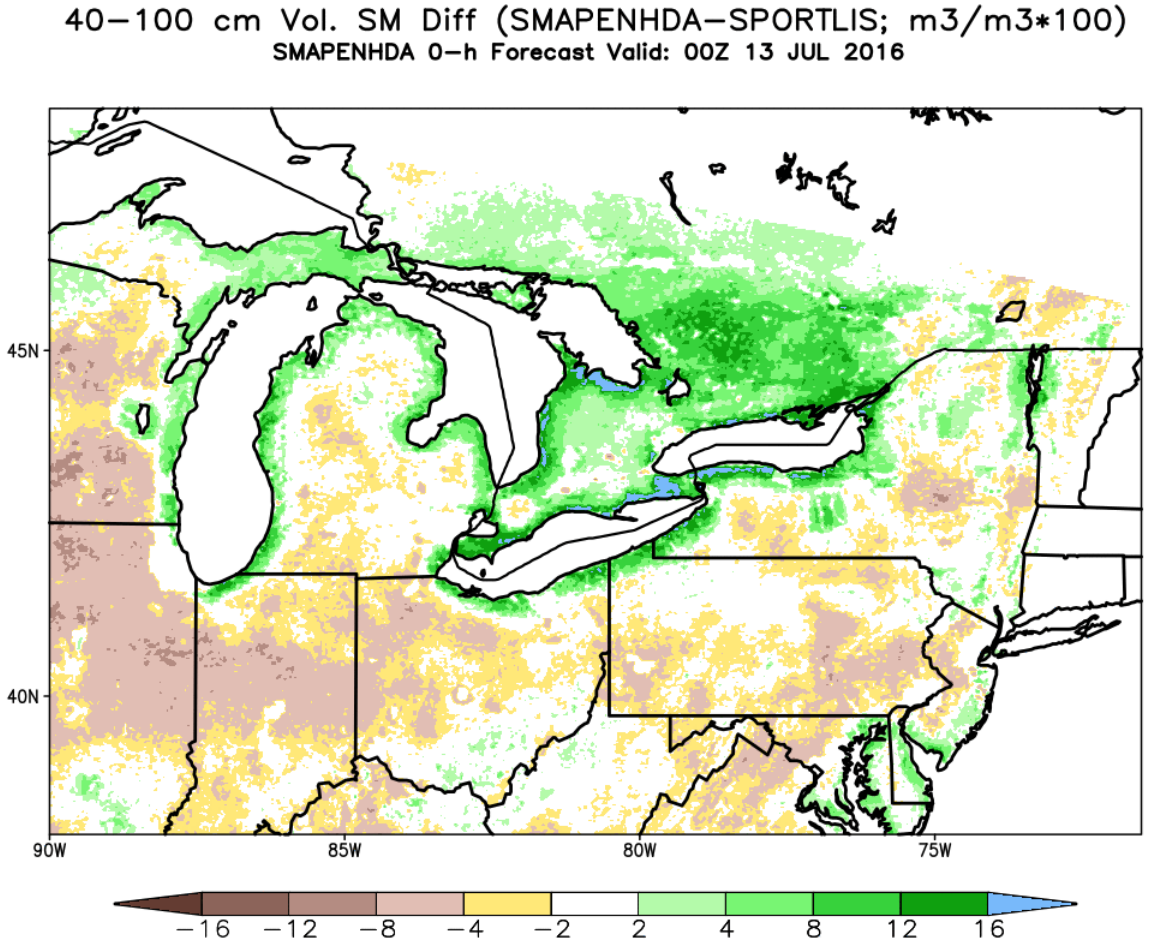


- Drier signal in Midwest/Cornbelt;
- More moist in SE Canada (corrected dry artifact in SPoRT-LIS soils)

00z 13 July Soil Moisture Initialization Differences:

40-100 cm volumetric soil moisture

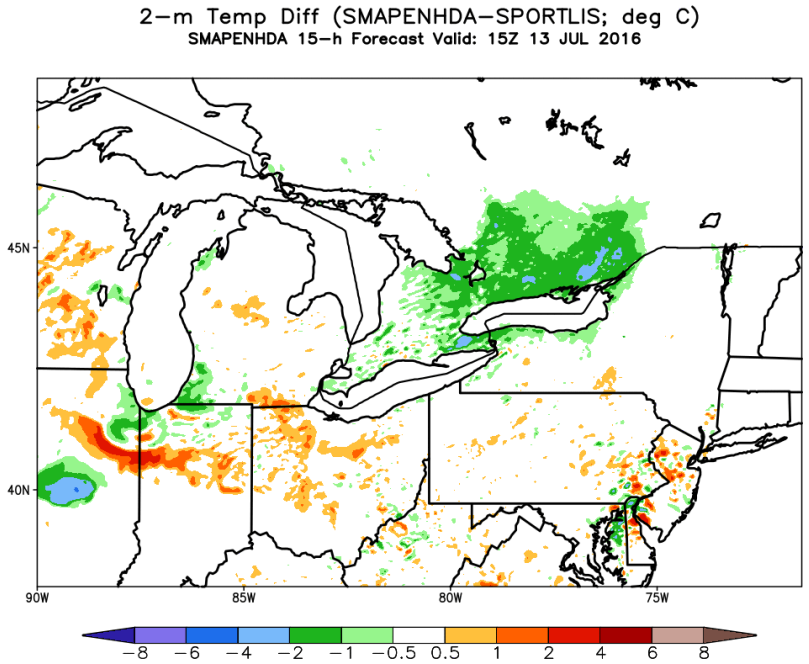


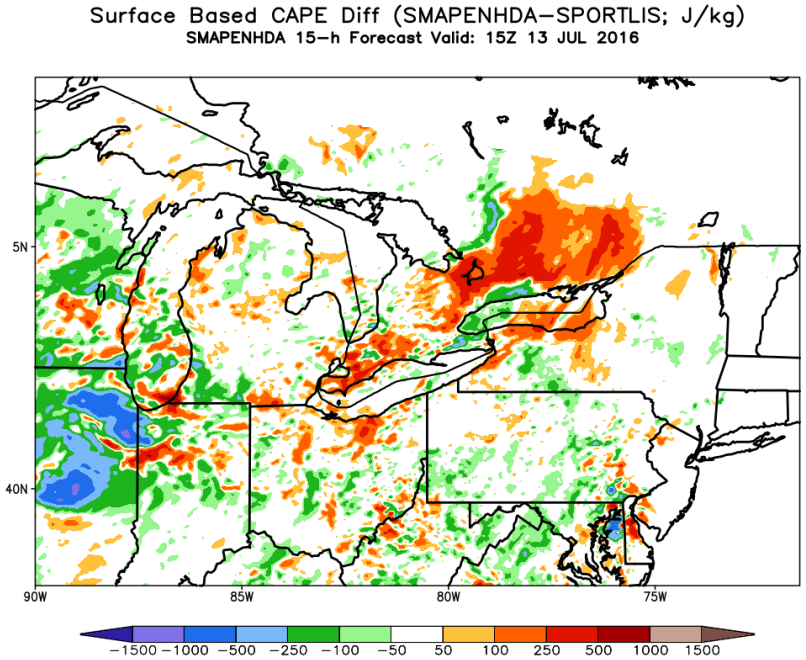


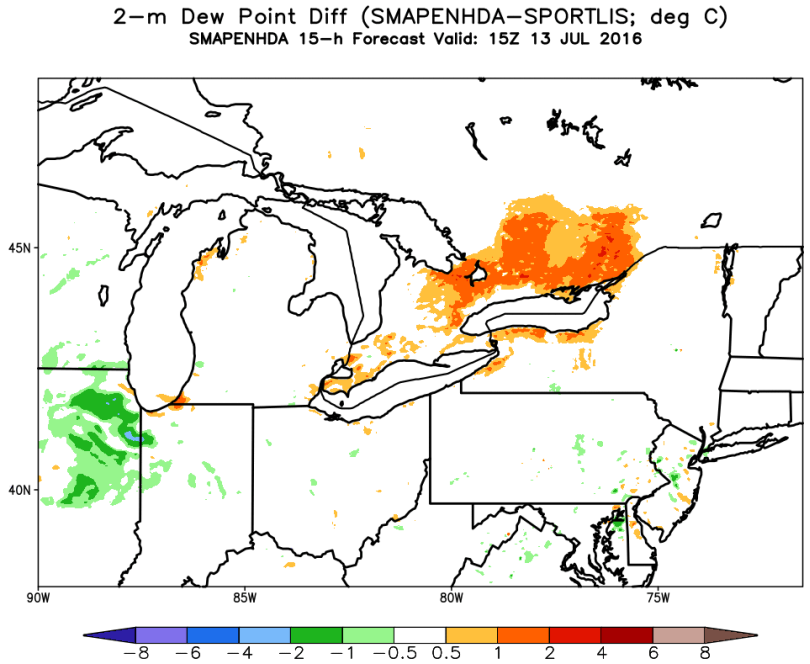
- Drier signal in Midwest/Cornbelt;
- More moist in SE Canada (corrected dry artifact in SPoRT-LIS soils)

13 July 2-m Temp/Dewp/SBCAPE Differences:

15-h forecast valid 15z 13 July



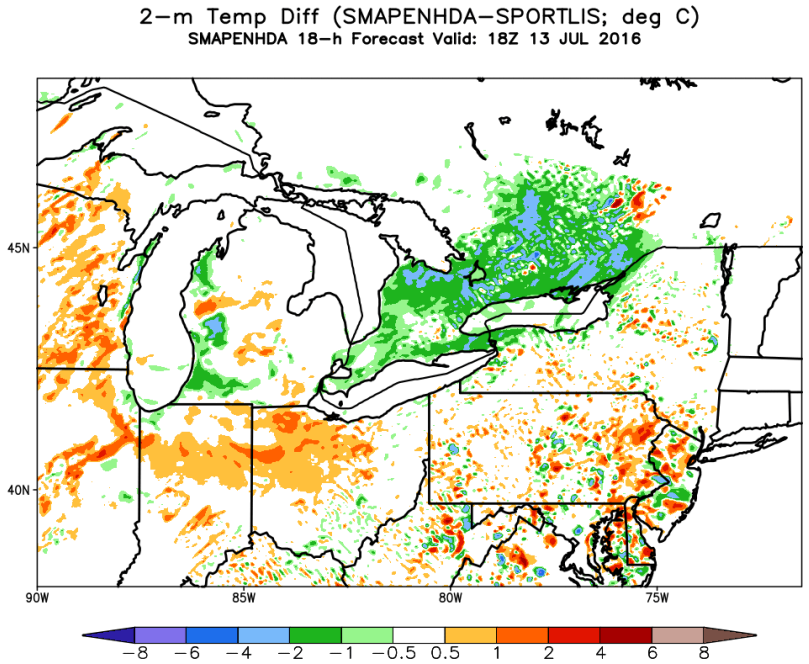


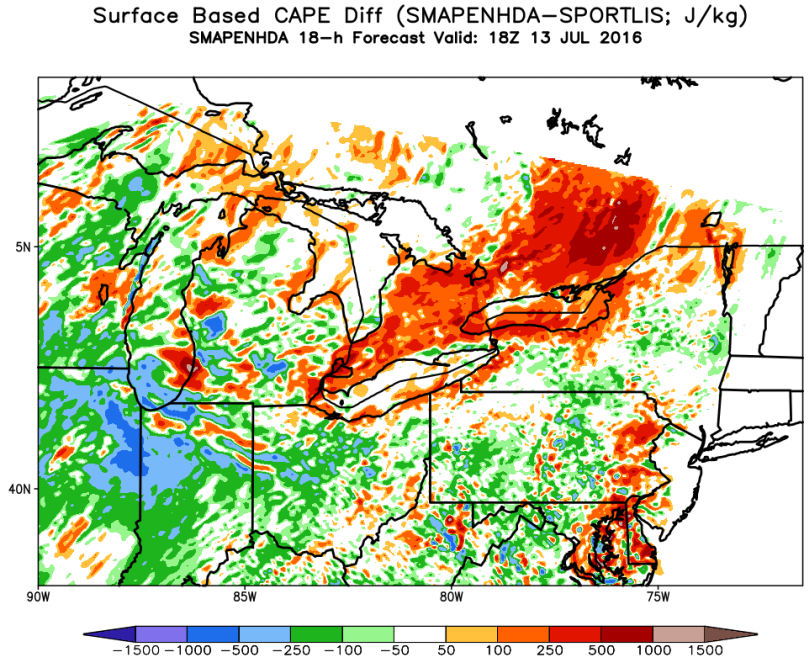


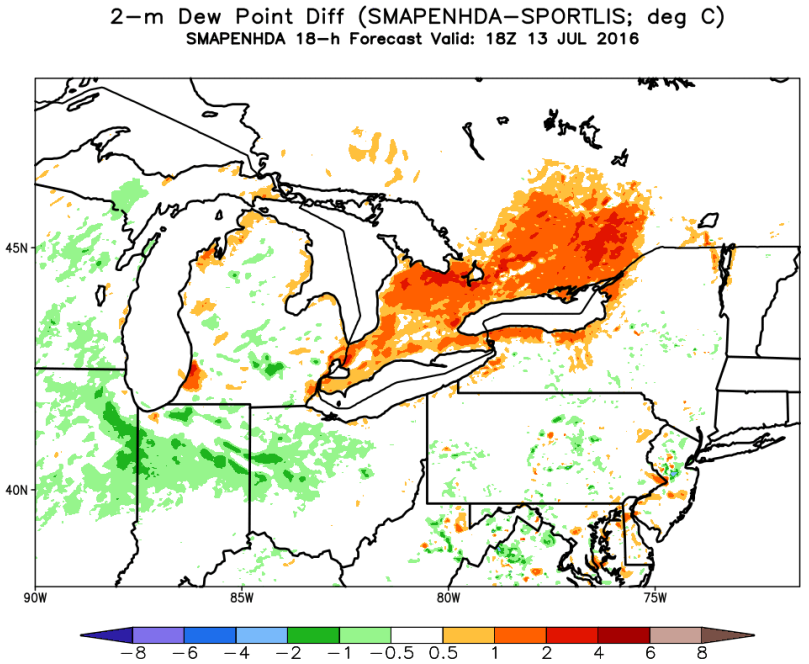
- Warmer/drier/less unstable in Midwest/Cornbelt;
- Cooler/more moist/more unstable in SE Canada

13 July 2-m Temp/Dewp/SBCAPE Differences:

18-h forecast valid 18z 13 July



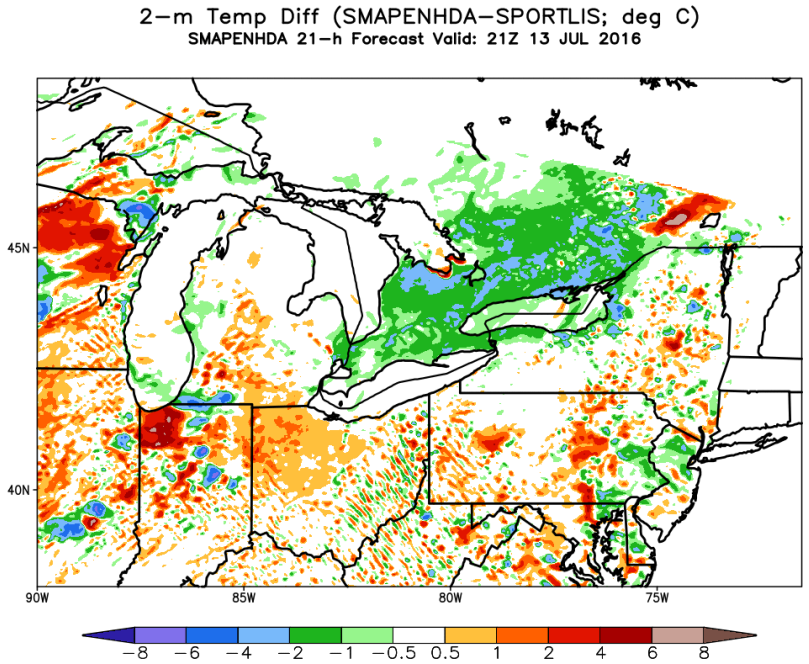


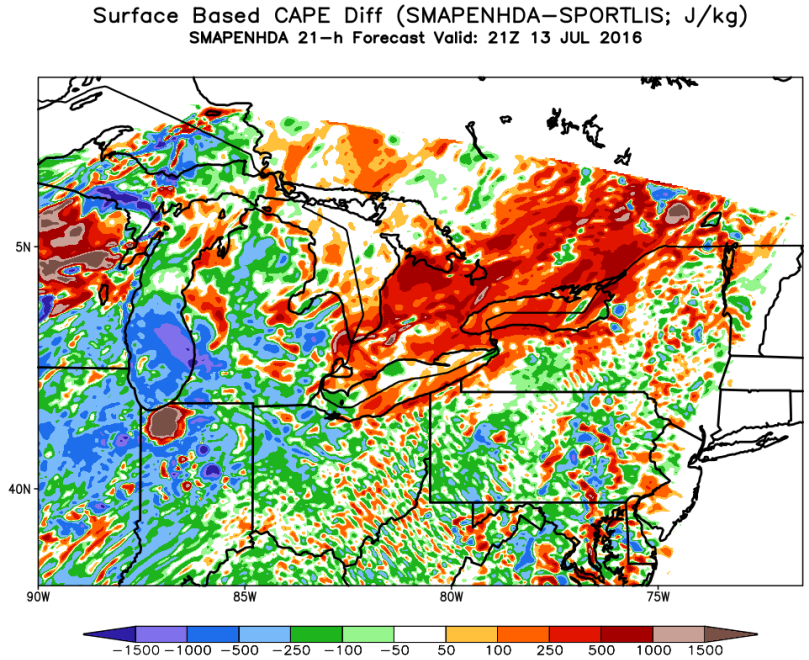


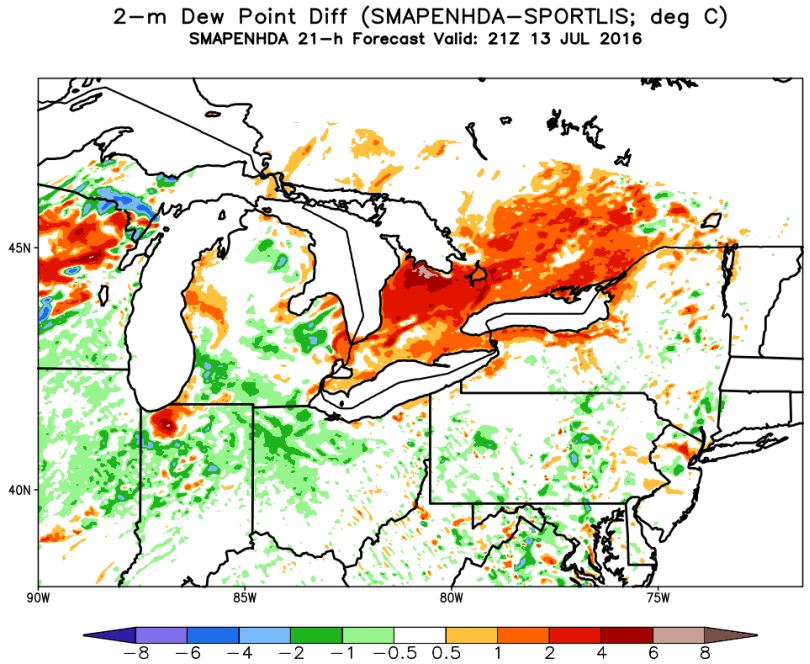
- Warmer/drier/less unstable in Midwest/Cornbelt;
- Cooler/more moist/more unstable in SE Canada

13 July 2-m Temp/Dewp/SBCAPE Differences:

21-h forecast valid 21z 13 July



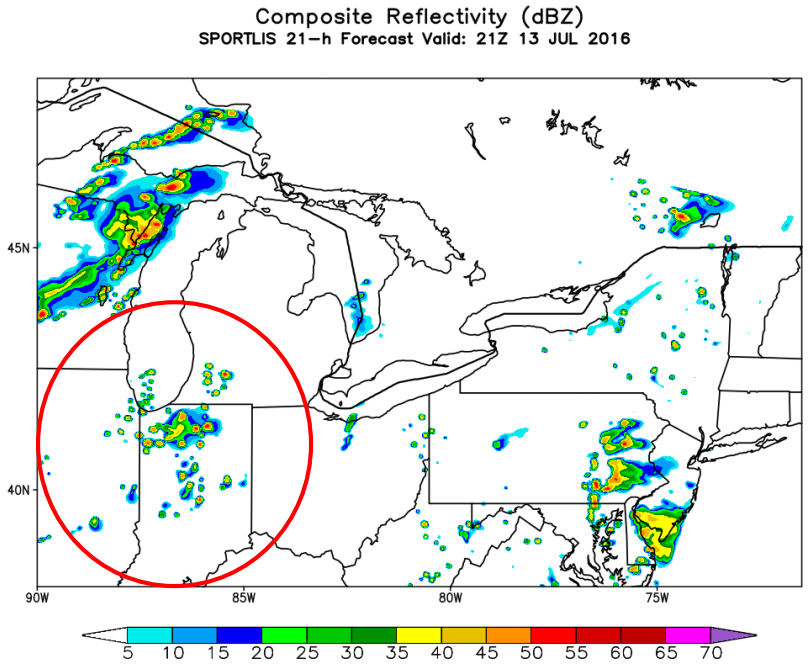




- Warmer/drier/less unstable in Midwest/Cornbelt;
- Cooler/more moist/more unstable in SE Canada

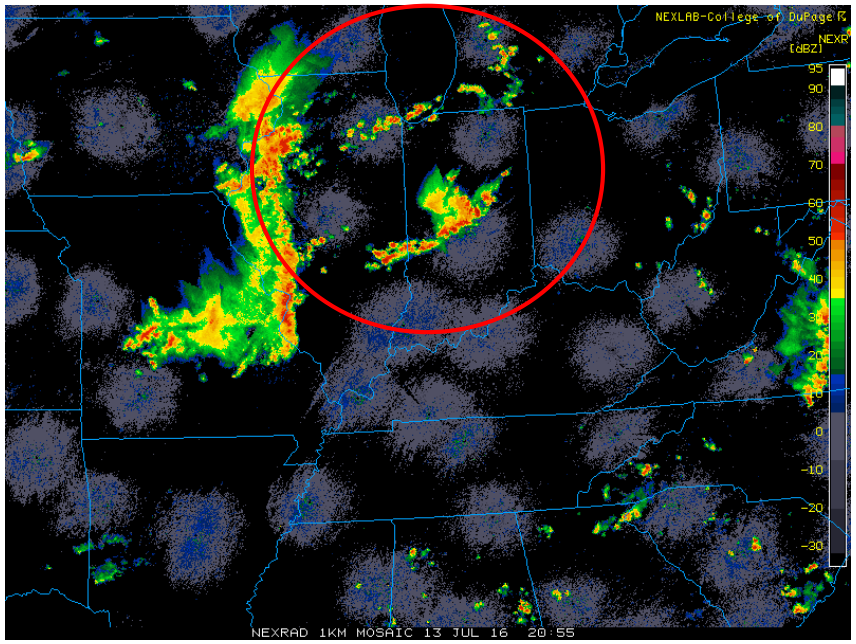
13-14 July Convection Evolution Differences:

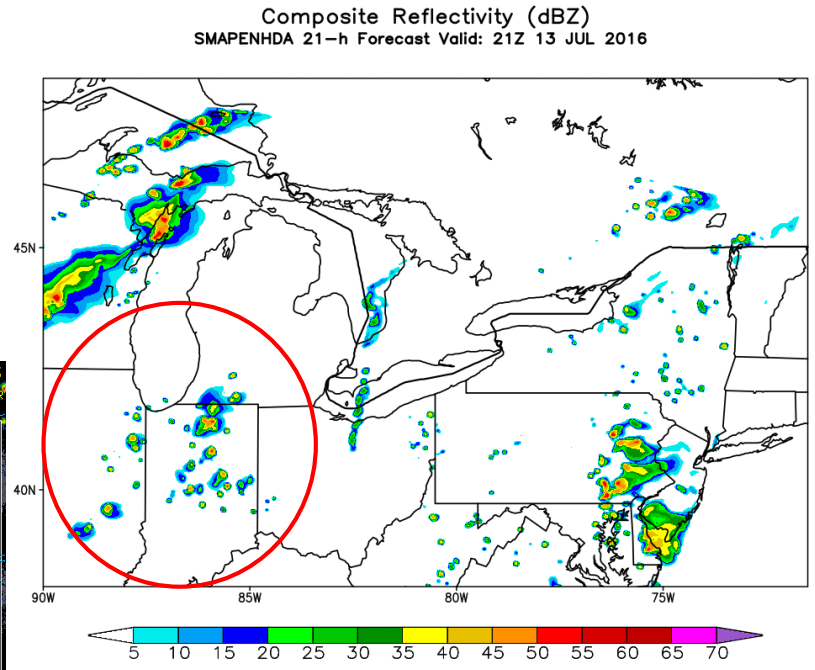
21-h forecast valid 21z 13 July



SPoRT-LIS (Control)

Observed Radar Composite



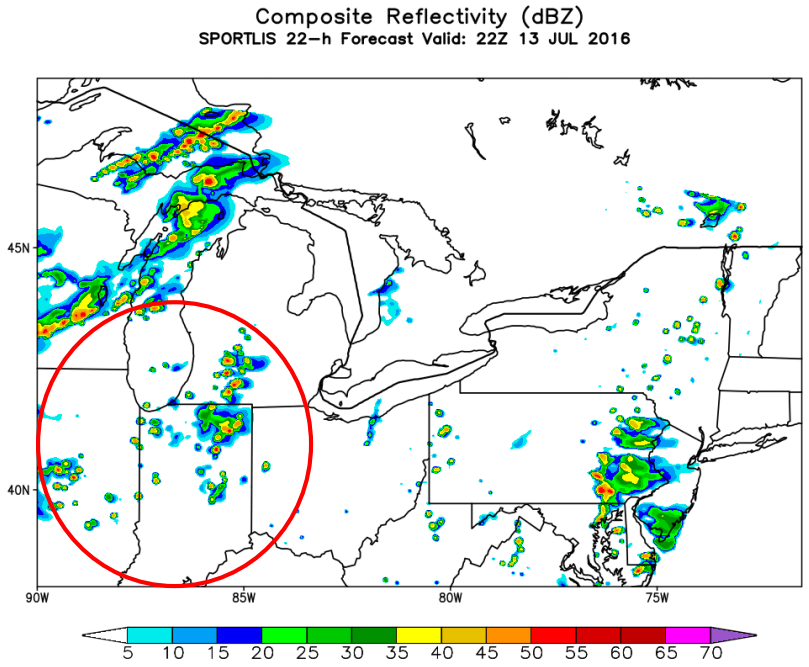


SMAP-Enh Data Assimilation

- SPoRT-LIS (left) squall line too slow, esp. earlier in late aft/early eve.
- SMAP-Enh DA (right) more correctly has faster propagation, but still too slow, esp. late eve.

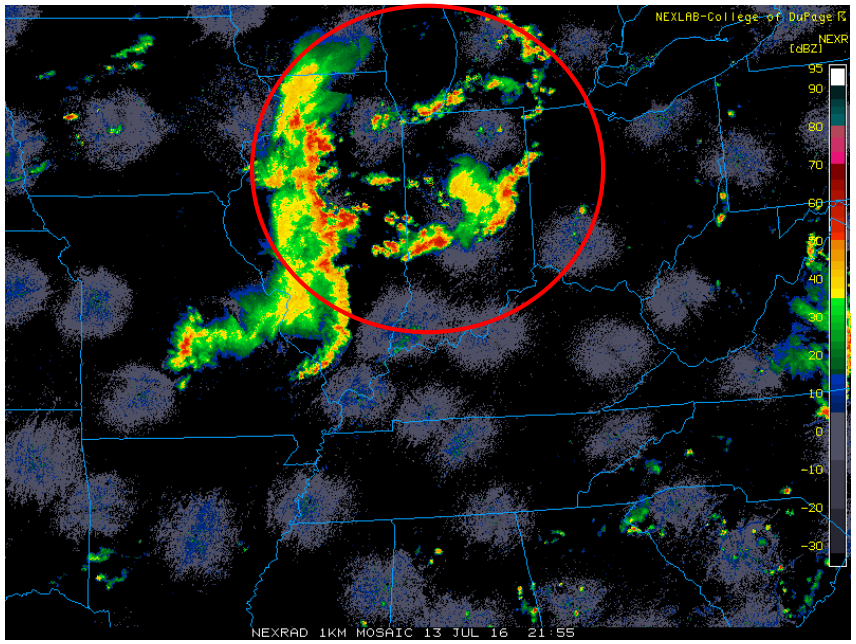
13-14 July Convection Evolution Differences:

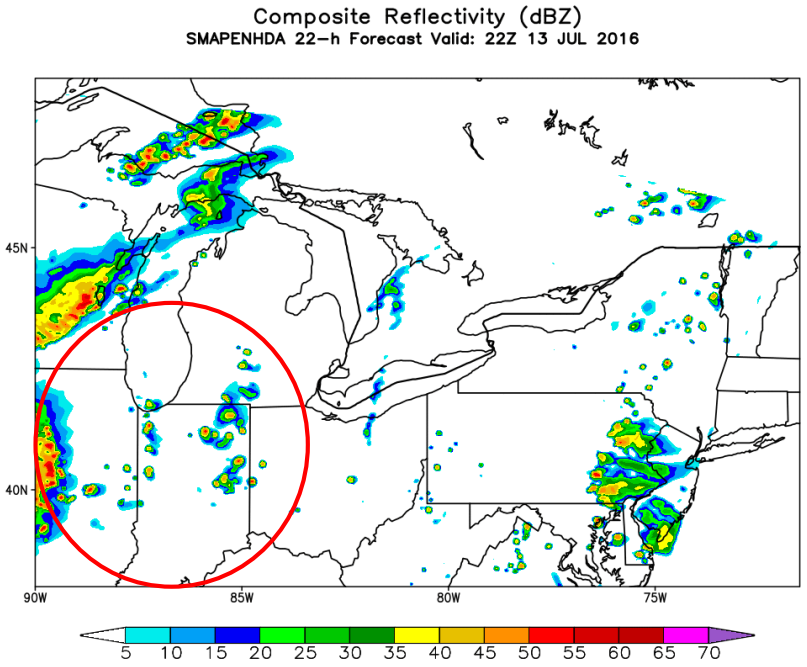
22-h forecast valid 22z 13 July



SPoRT-LIS (Control)

Observed Radar Composite



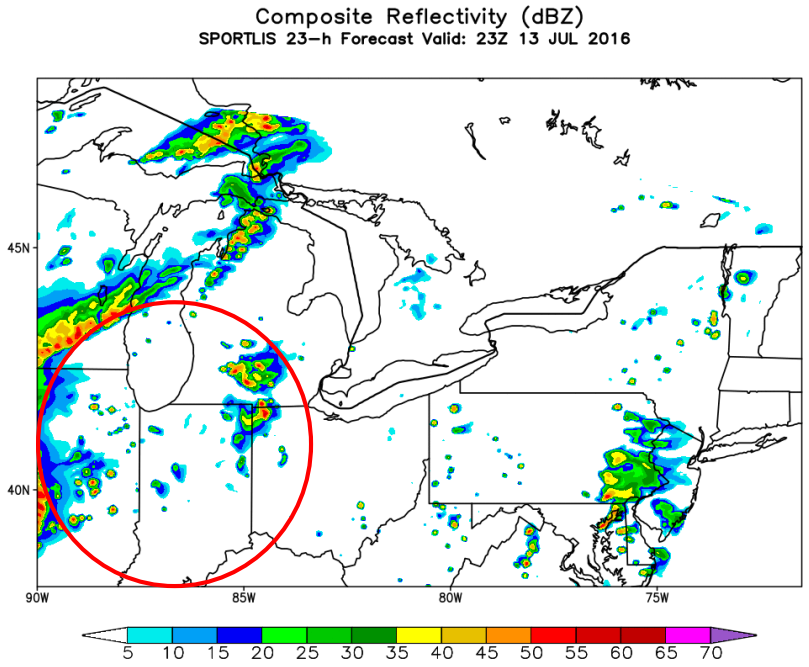


SMAP-Enh Data Assimilation

- SPoRT-LIS (left) squall line too slow, esp. earlier in late aft/early eve.
- SMAP-Enh DA (right) more correctly has faster propagation, but still too slow, esp. late eve.

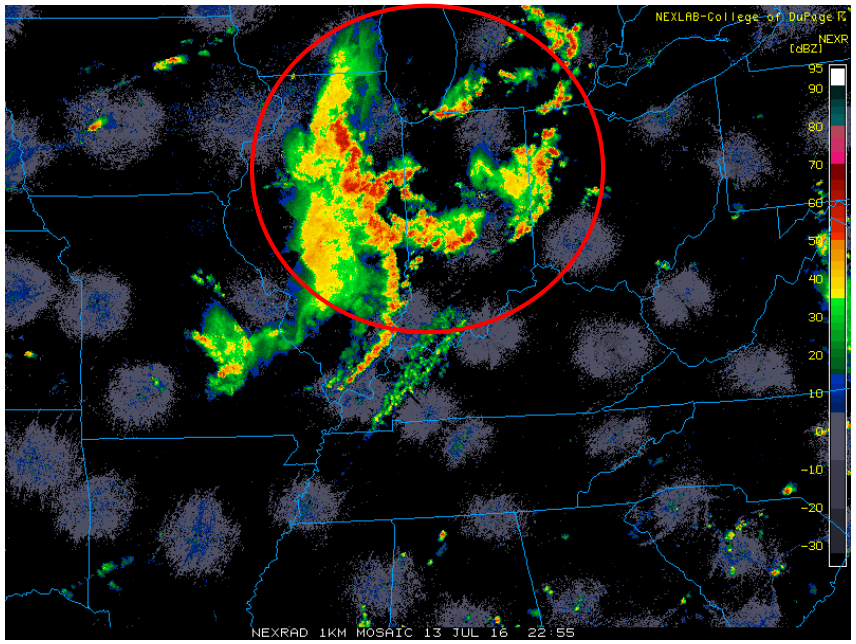
13-14 July Convection Evolution Differences:

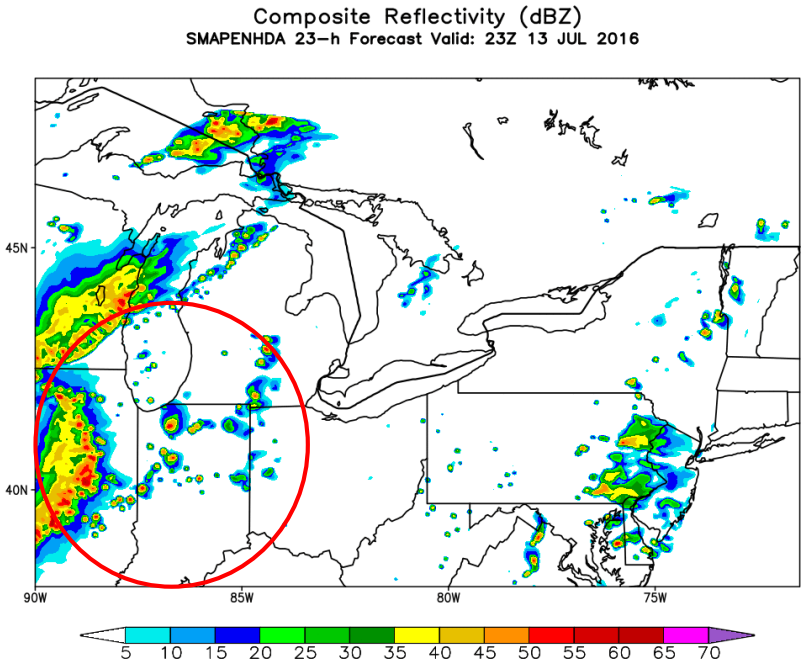
23-h forecast valid 23z 13 July



SPoRT-LIS (Control)

Observed Radar Composite



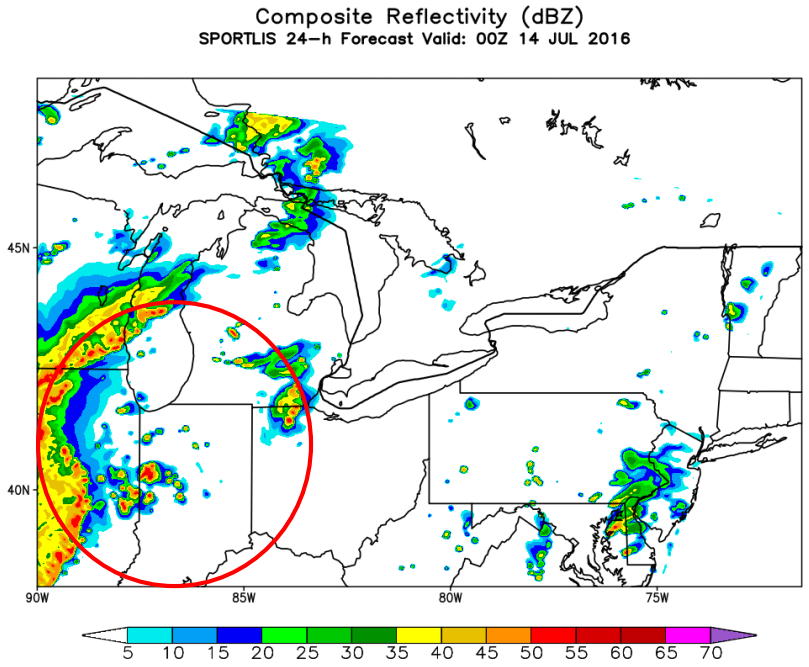


SMAP-Enh Data Assimilation

- SPoRT-LIS (left) squall line too slow, esp. earlier in late aft/early eve.
- SMAP-Enh DA (right) more correctly has faster propagation, but still too slow, esp. late eve.

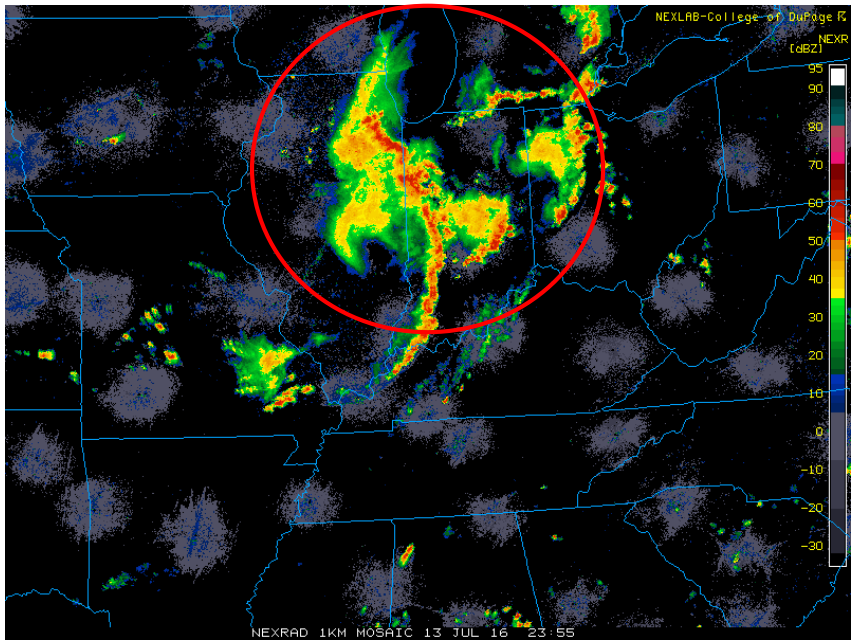
13-14 July Convection Evolution Differences:

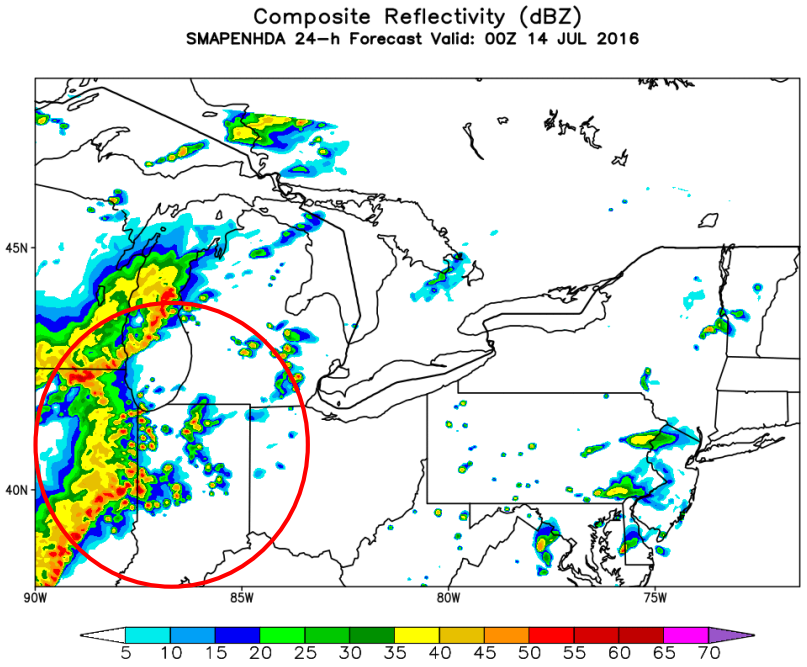
24-h forecast valid 00z 14 July



SPoRT-LIS (Control)

Observed Radar Composite





SMAP-Enh Data Assimilation

- SPoRT-LIS (left) squall line too slow, esp. earlier in late aft/early eve.
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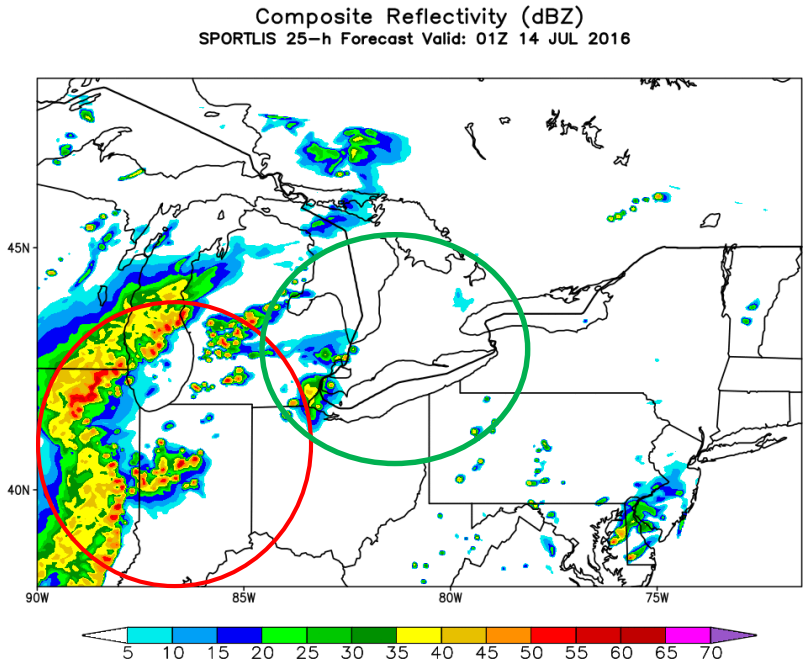
13-14 July Convection Evolution Differences:

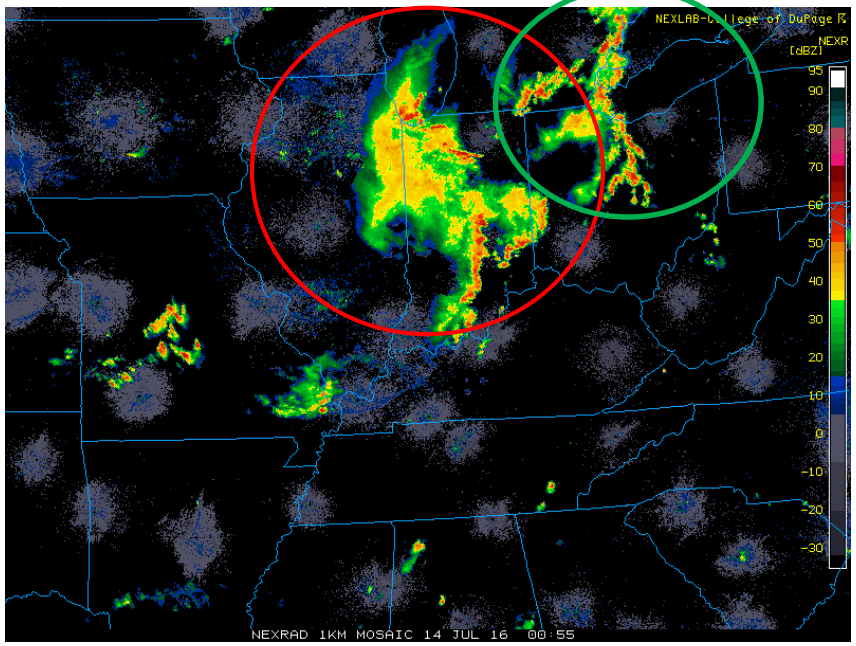
25-h forecast valid 01z 14 July

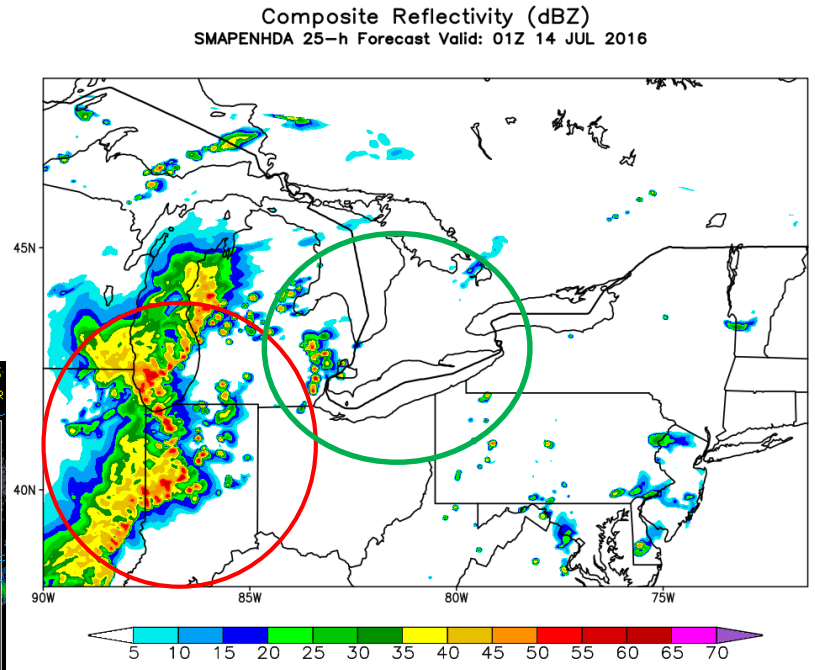


SPoRT-LIS (Control)

- **SPoRT-LIS mostly misses secondary line development in Ontario/Ohio**

Observed Radar Composite





SMAP-Enh Data Assimilation

- **SMAP-Enh DA simulates secondary line, but mainly over Ontario**

- SPoRT-LIS (left) squall line too slow, esp. earlier in late aft/early eve.
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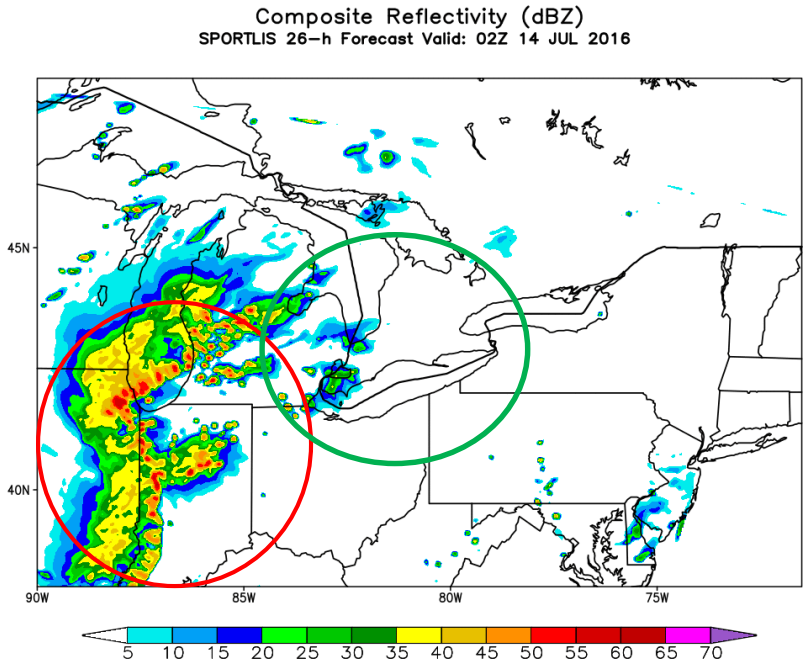
13-14 July Convection Evolution Differences:

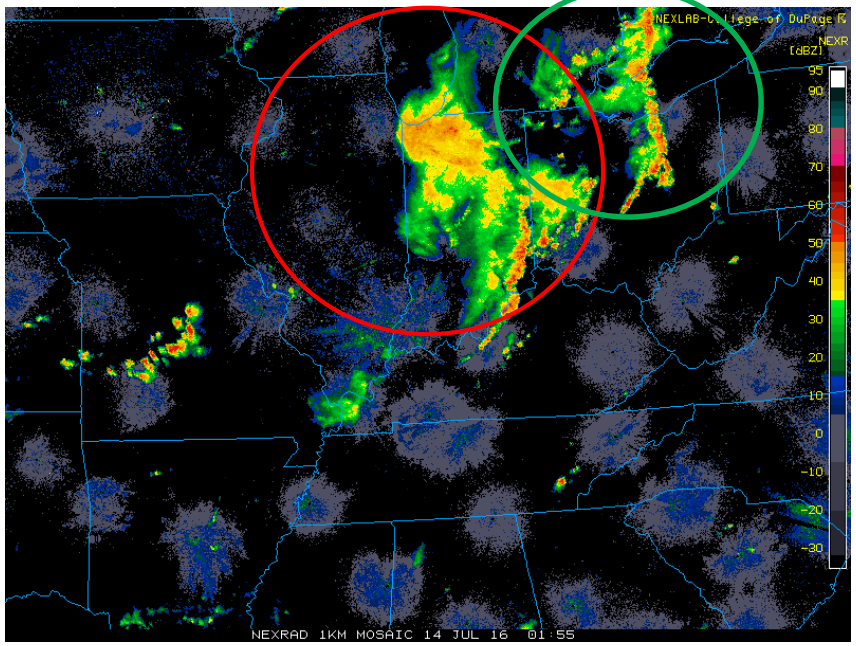
26-h forecast valid 02z 14 July

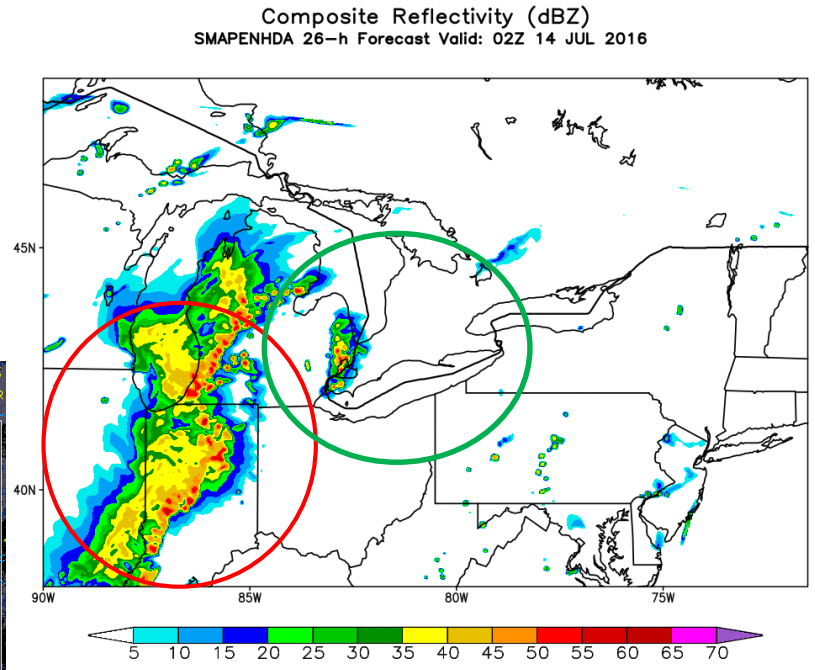


SPoRT-LIS (Control)

- **SPoRT-LIS mostly misses secondary line development in Ontario/Ohio**

Observed Radar Composite





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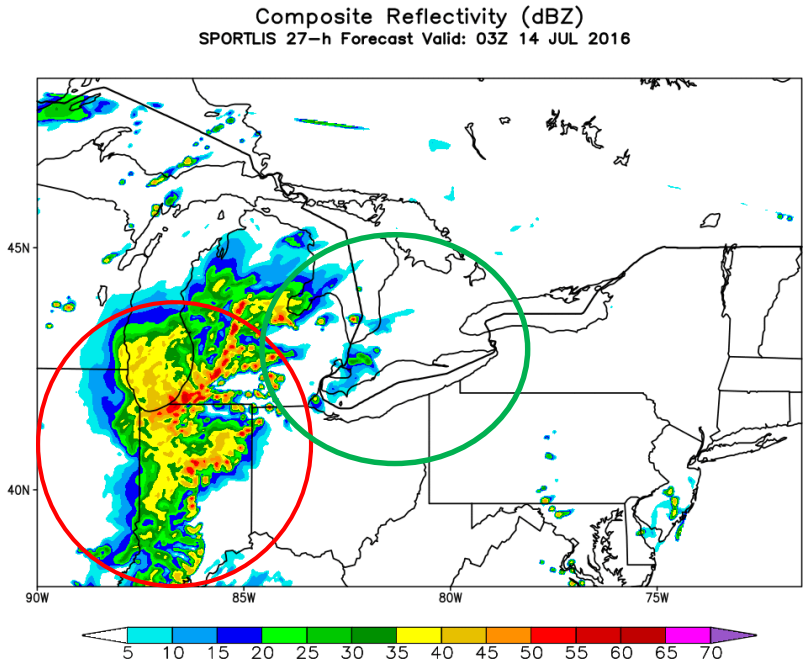
13-14 July Convection Evolution Differences:

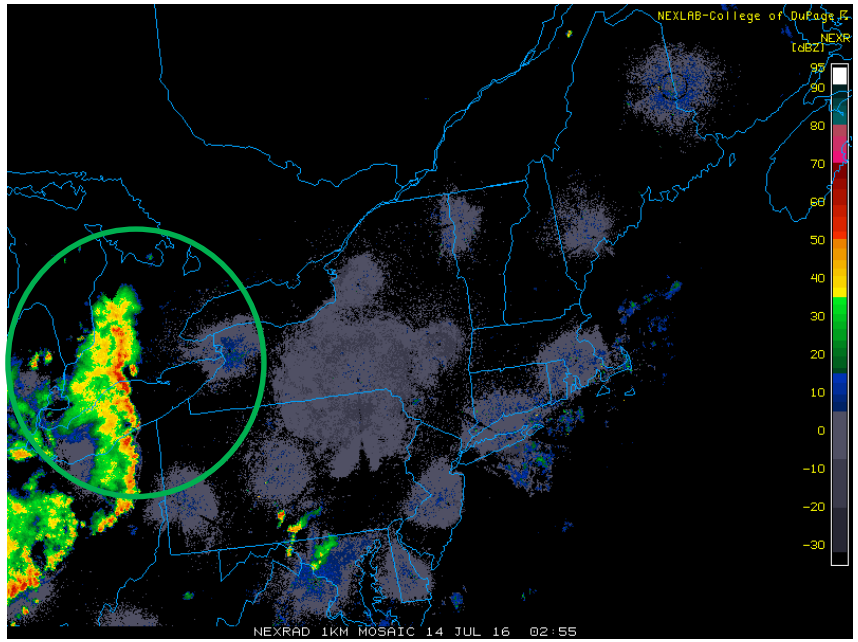
27-h forecast valid 03z 14 July

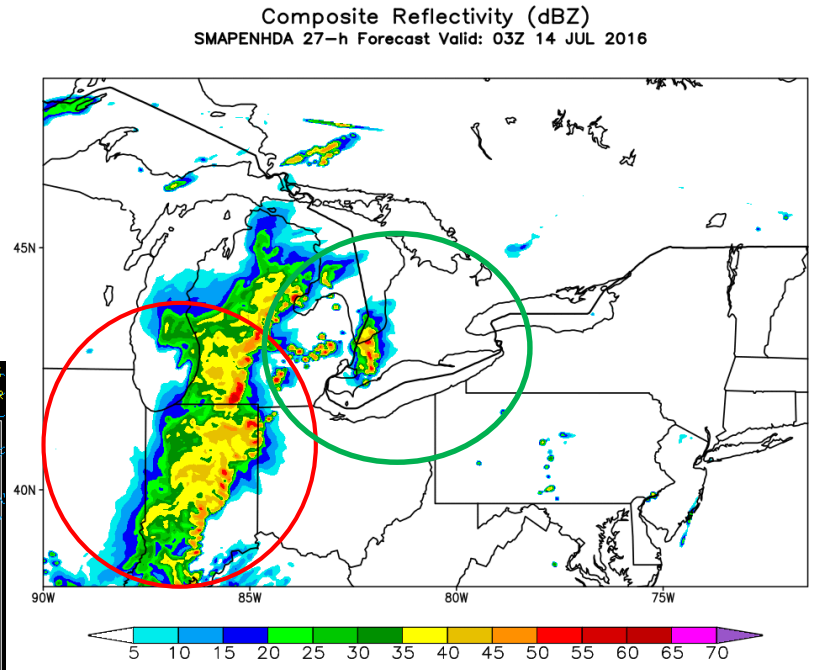


SPoRT-LIS (Control)

- **SPoRT-LIS mostly misses secondary line development in Ontario/Ohio**

Observed Radar Composite





SMAP-Enh Data Assimilation

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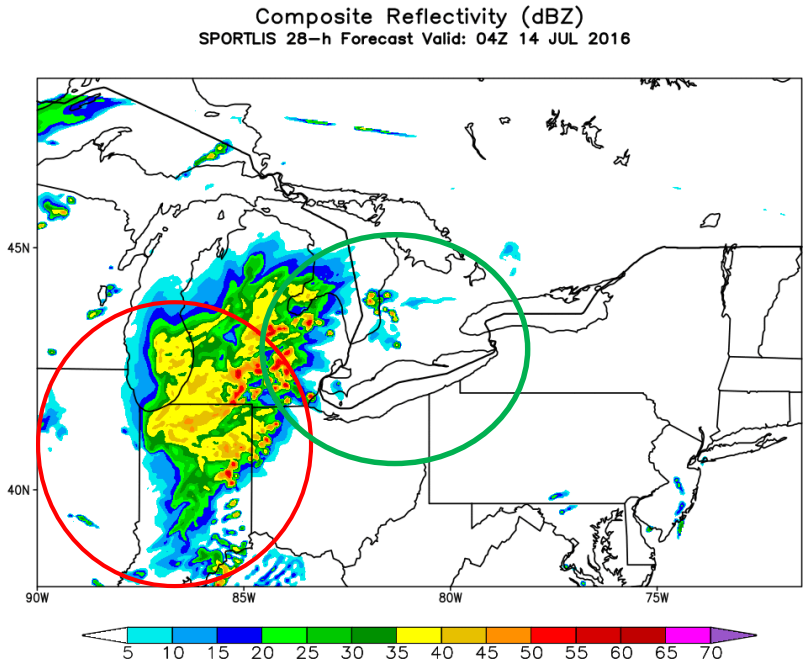
13-14 July Convection Evolution Differences:

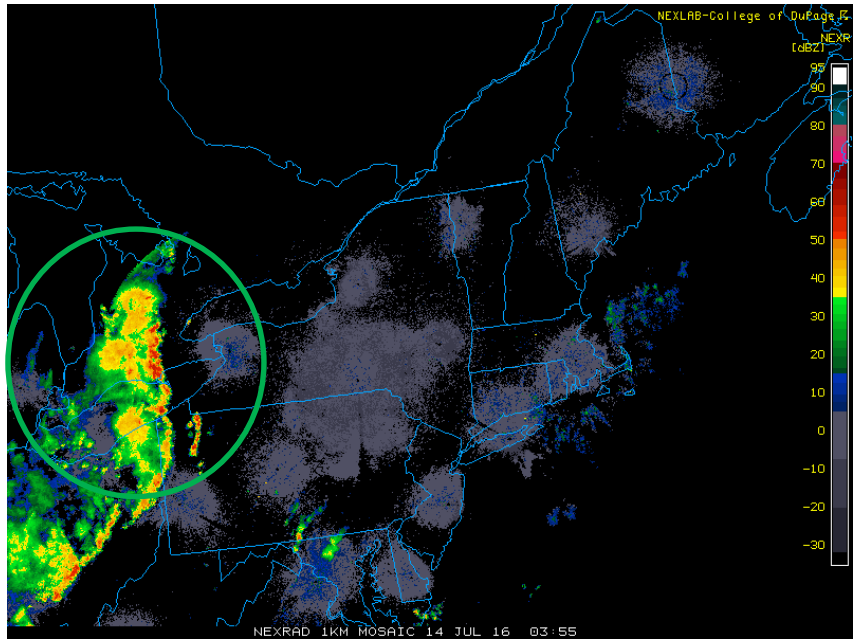
28-h forecast valid 04z 14 July

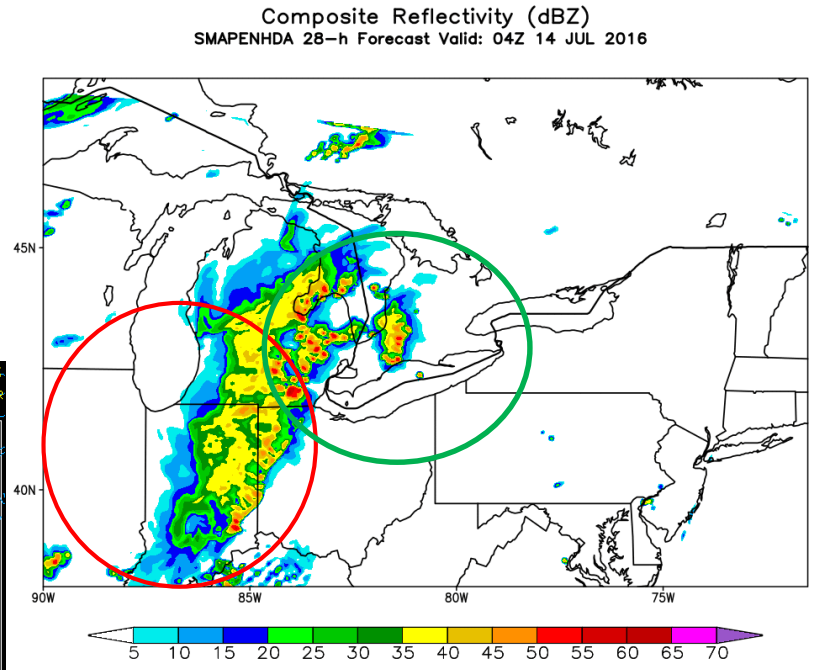


SPoRT-LIS (Control)

- **SPoRT-LIS mostly misses secondary line development in Ontario/Ohio**

Observed Radar Composite





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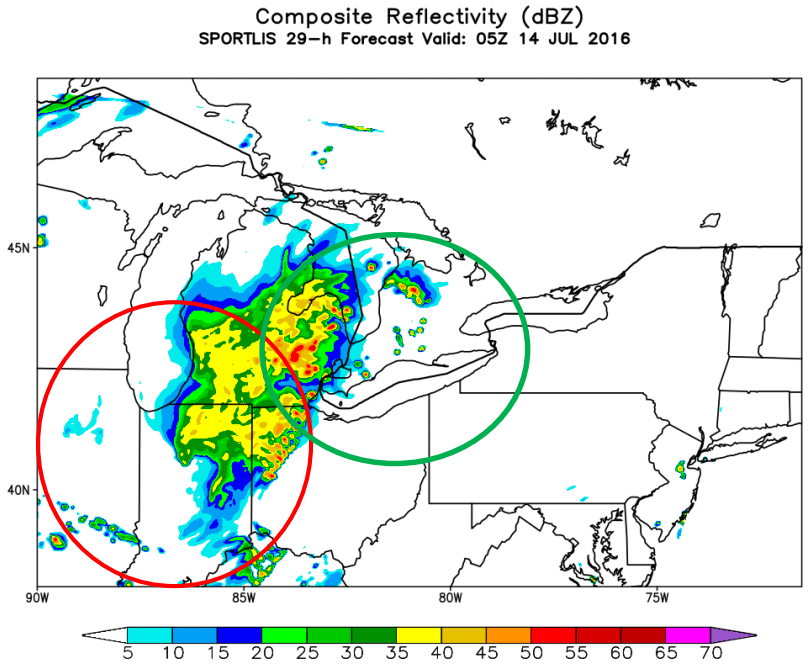
13-14 July Convection Evolution Differences:

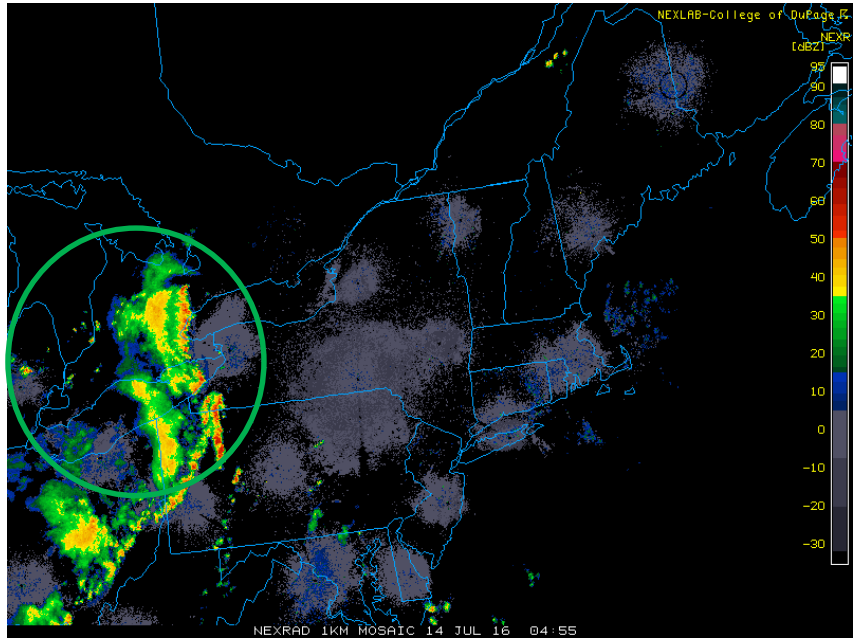
29-h forecast valid 05z 14 July

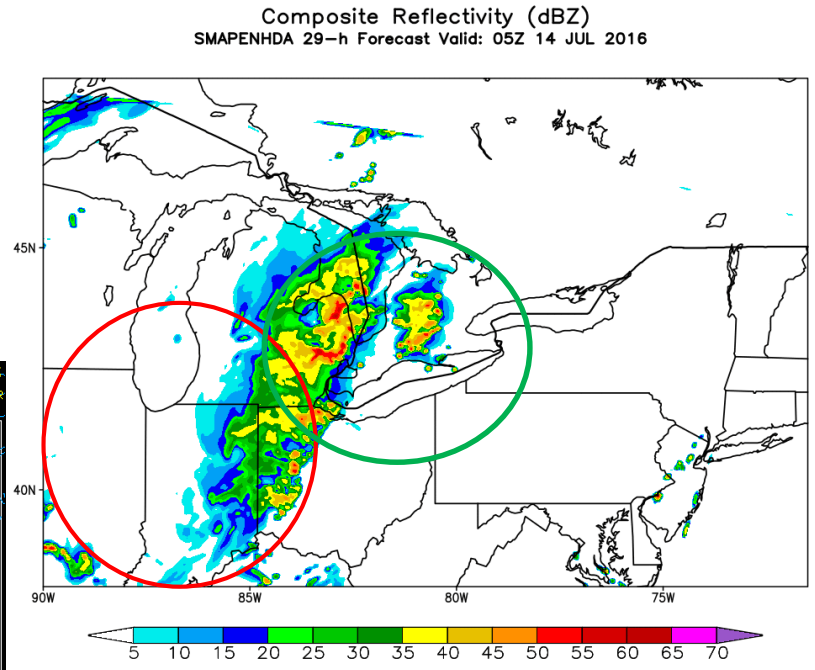


SPoRT-LIS (Control)

- **SPoRT-LIS mostly misses secondary line development in Ontario/Ohio**

Observed Radar Composite





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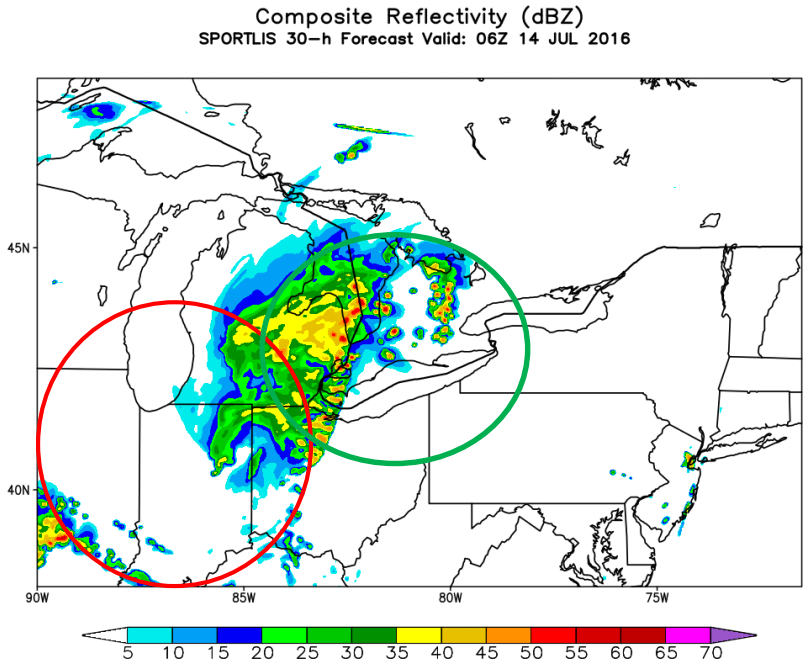
13-14 July Convection Evolution Differences:

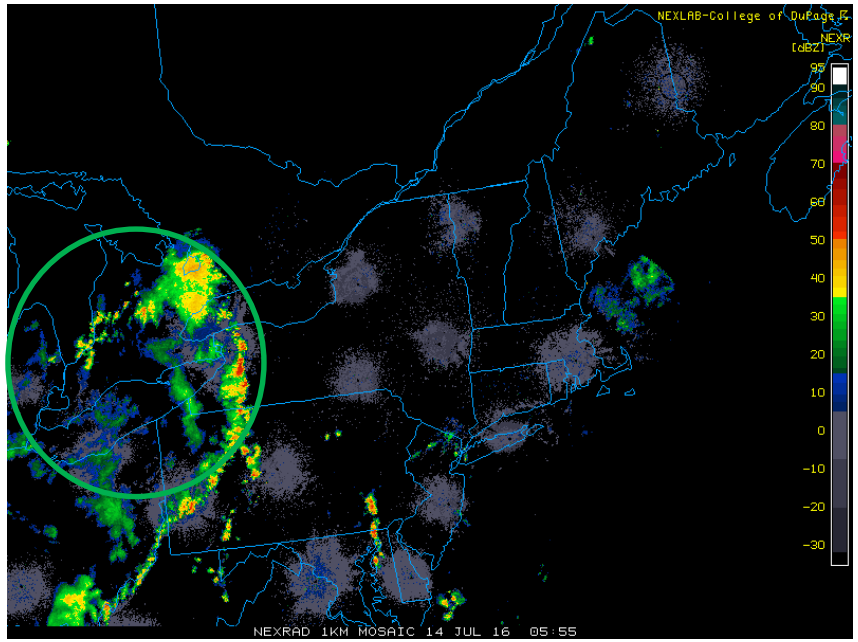
30-h forecast valid 06z 14 July

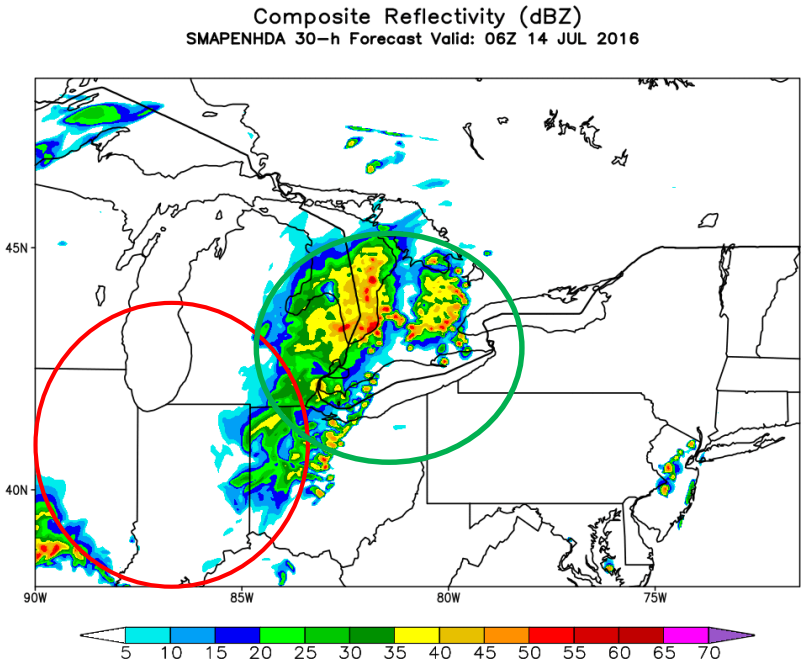


SPoRT-LIS (Control)

- **SPoRT-LIS mostly misses secondary line development in Ontario/Ohio**

Observed Radar Composite





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NWP Initialization Results

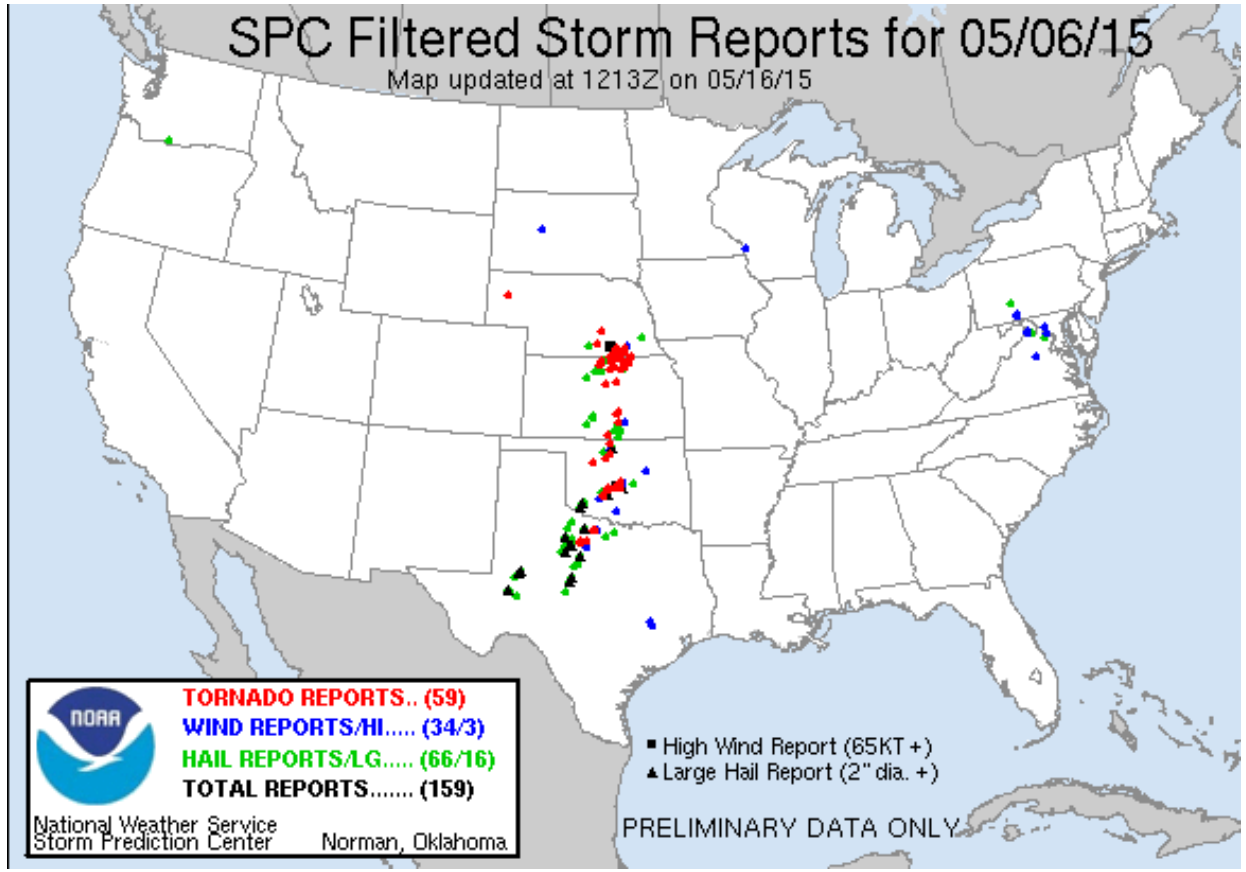
WRF case over Southern Plains

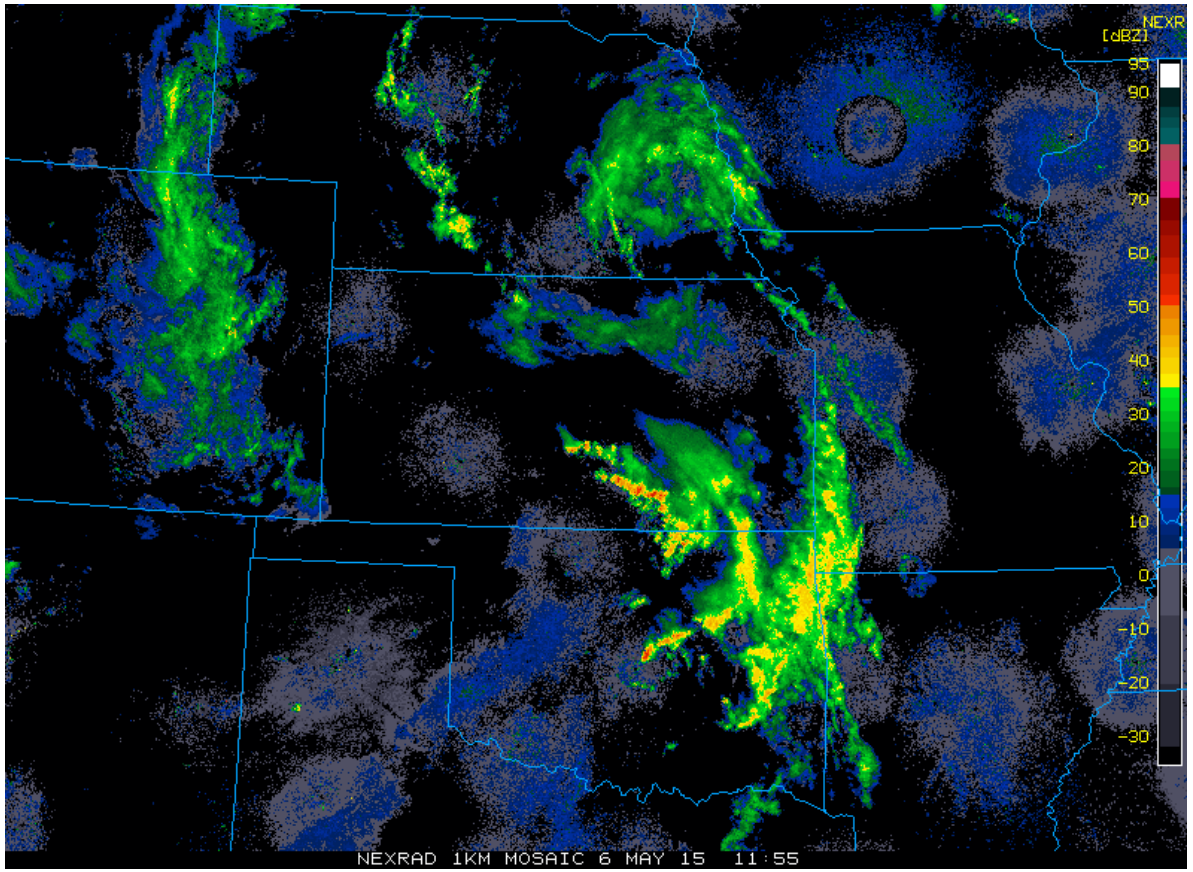
SPoRT-LIS vs. SMAP-Enh DA initialized runs

[6-7 May 2015 tornado outbreak]

6-7 May 2015 Southern Plains tornado outbreak:

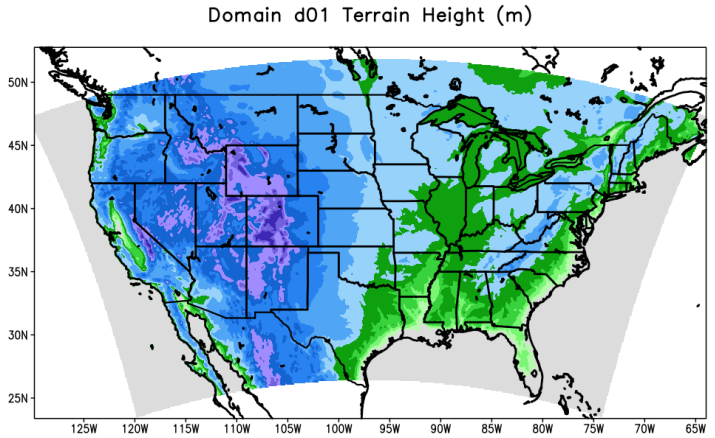
NASA Unified-WRF (NU-WRF) sensitivity simulations



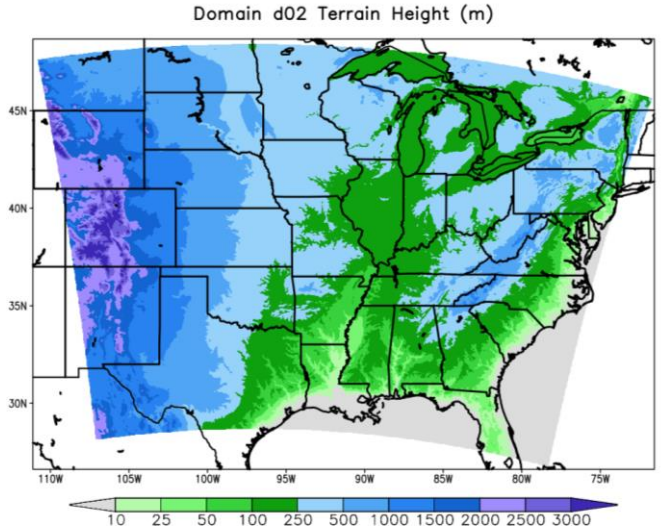


NASA Unified-WRF (NU-WRF) model runs:
Model configuration and experiment details

- Domain/grid set up (images at right)
  - *Contiguous U.S. at 9-km horizontal grid spacing*
  - *Convection-allowing 3-km mesh nested grid*
- Sixty-hour forecasts
  - *0000 UTC 6 May to 1200 UTC 8 May*
  - *Initialized at 0000 UTC 6 May 2015*
  - *Initial/boundary conditions from NCEP Global Forecast System model*
- Model physics parameterization choices
  - *Noah land surface model (same as in LIS runs)*
  - *Convection: Scale-aware Kain-Fritsch (9-km grid only)*
  - *Planetary Boundary Layer: Yonsei University scheme*
  - *Microphysics: NASA/Goddard 4-ice parameterization*
  - *Radiation: NASA/Goddard short- and long-wave radiation schemes*
- Two land surface initialization simulations
  - ***"sportlis":*** *0-h land surface fields from SPoRT's "operational" LIS run; no DA*
  - ***"smapenhda":*** *0-h land surface fields from SMAP-Enhanced DA LIS run*

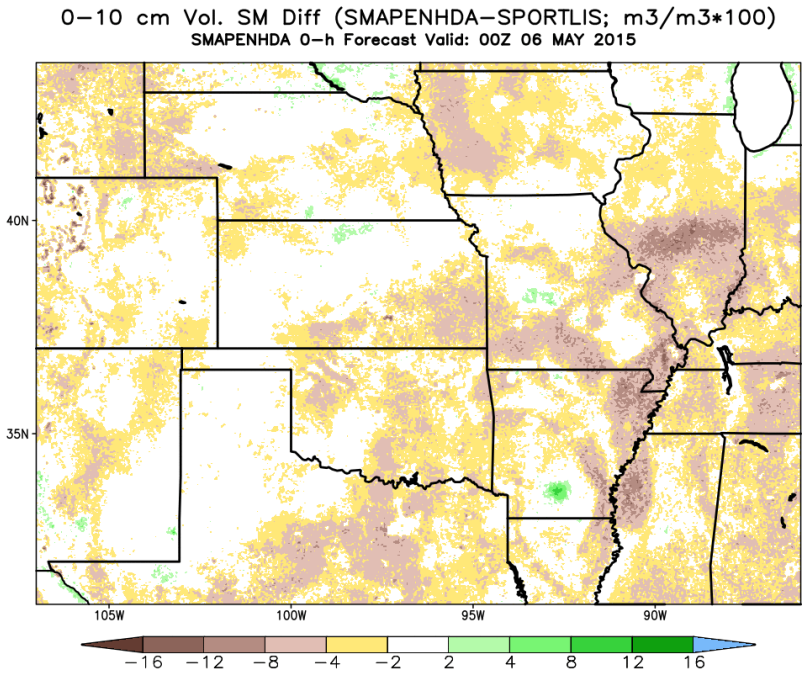


9-km primary grid



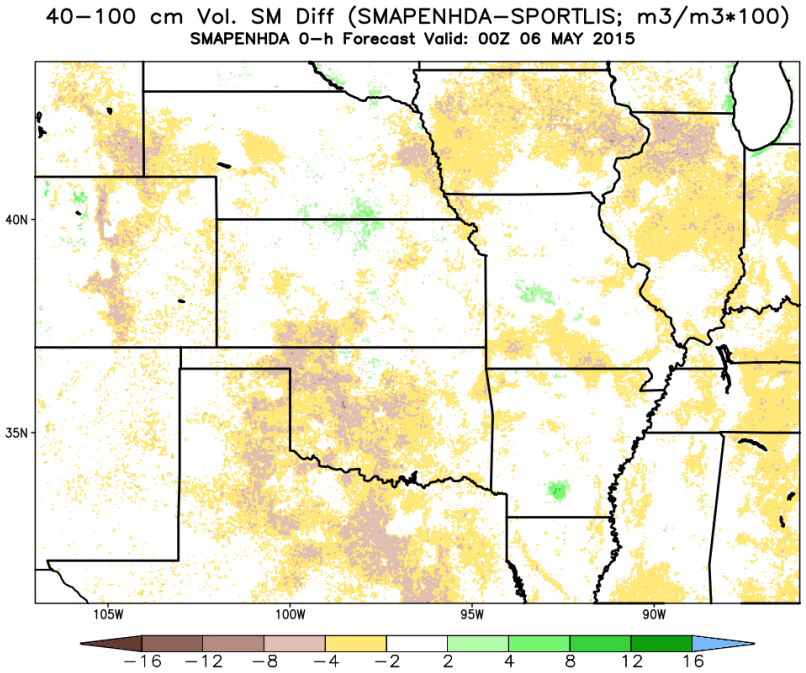
3-km nested grid

NASA Unified-WRF (NU-WRF) model runs:
Soil Moisture Initial Condition Differences on 3-km nest

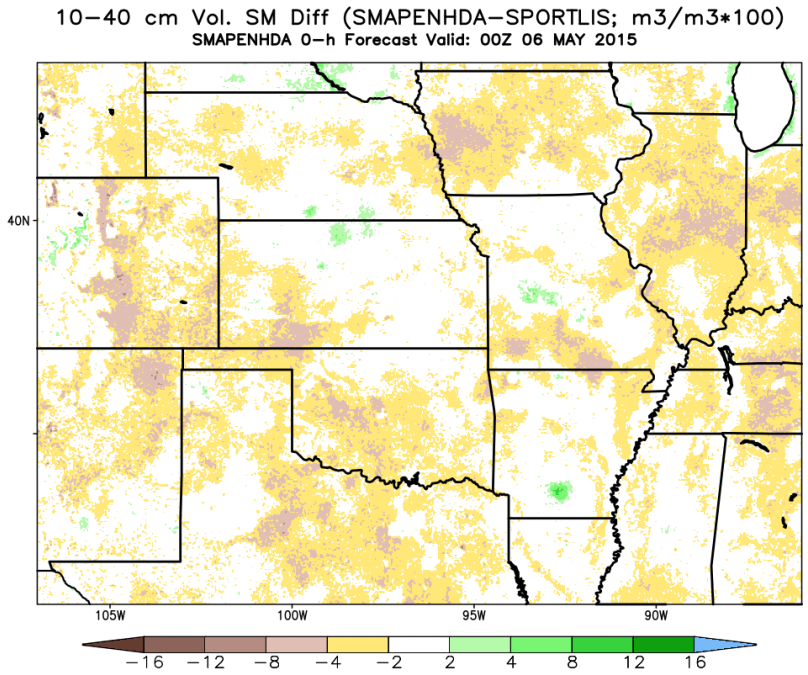


Top soil layer (0-10 cm)

SMAP-Enhanced data assimilation run generally produced drier soil moisture fields than sportlis.

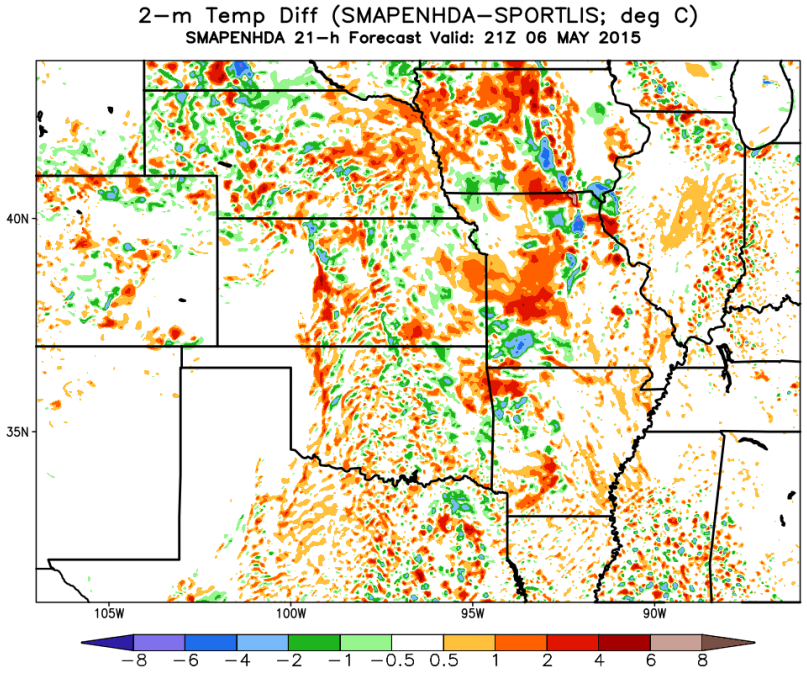


Soil layer 3 (40-100 cm)



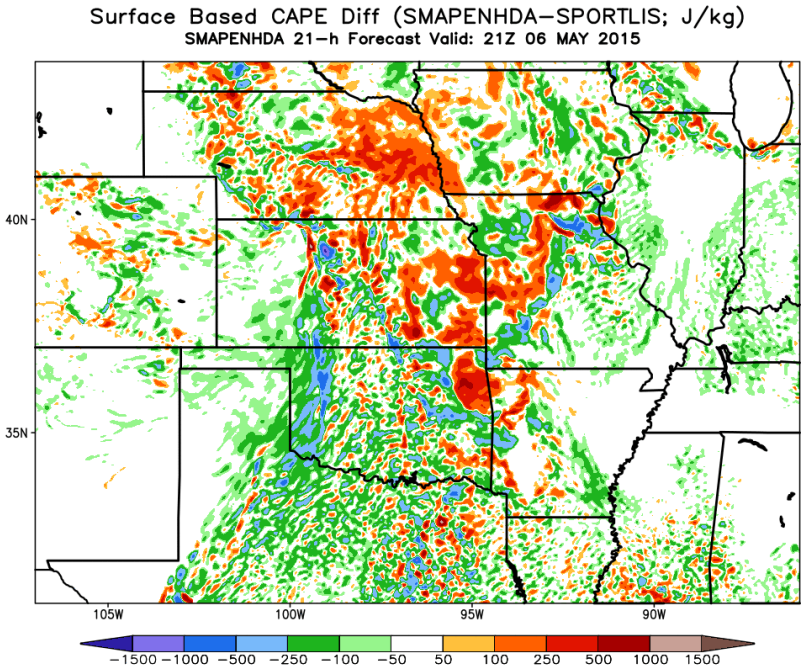
Soil layer 2 (10-40 cm)

NASA Unified-WRF (NU-WRF) model runs:
Slight improvement in simulated convective evolution

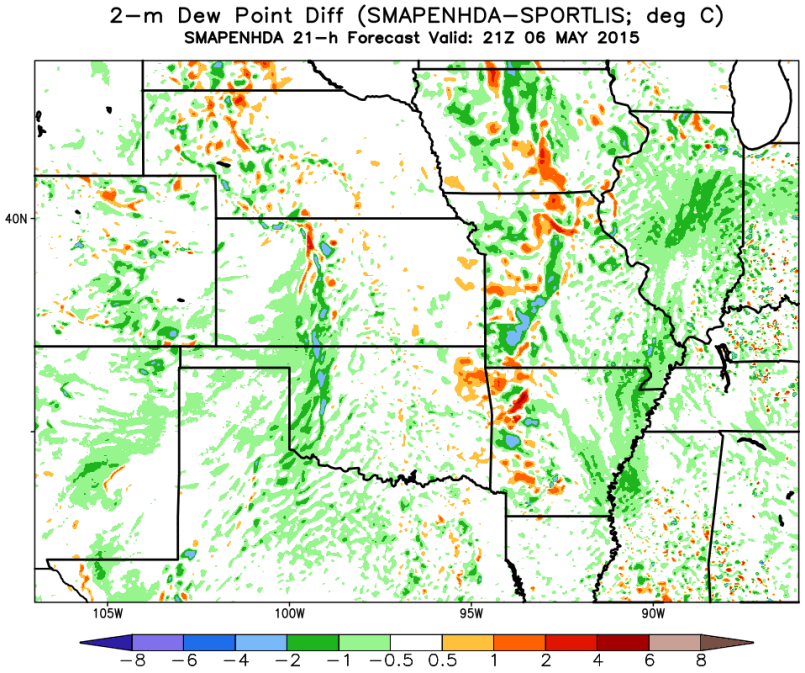


2-m Temperature

smapenhda-initialized NU-WRF runs generally simulated warmer/drier daytime temperatures/dewpoints, with slightly lower instability where convection/supercells developed.



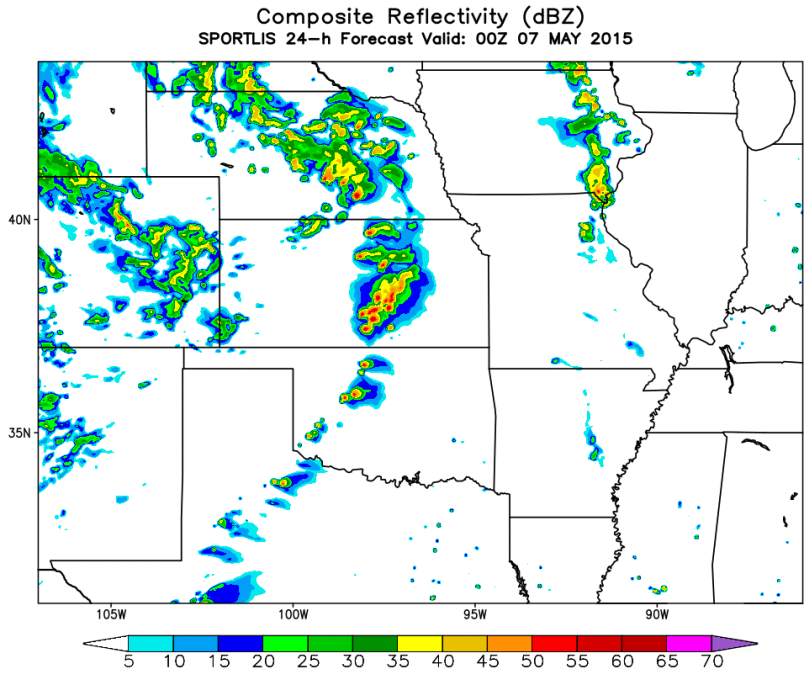
Sfc-based Convective Available Potential Energy



2-m Dewpoint Temperature

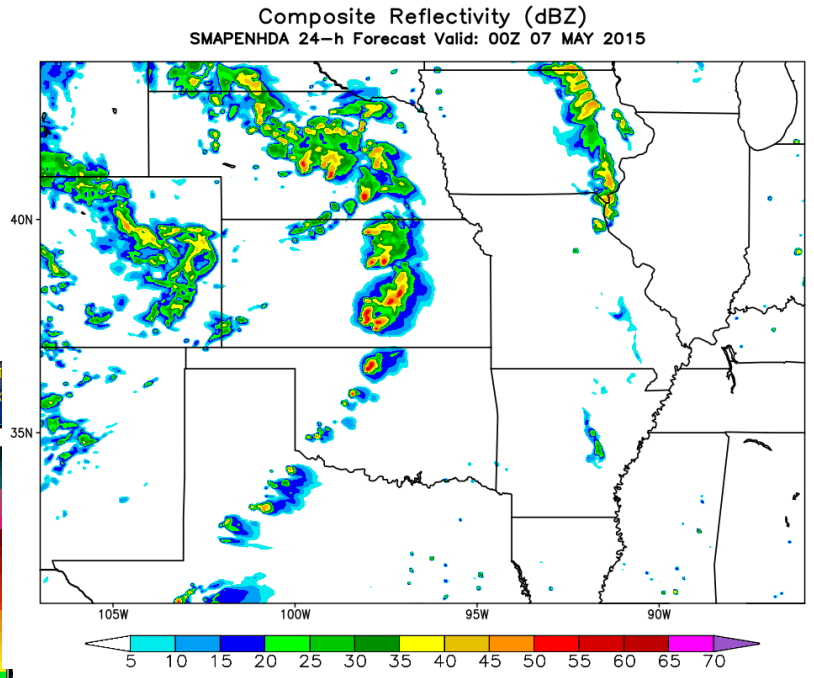
*****All simulated fields shown are from the 21-hour NU-WRF forecast, valid on 2100 UTC 6 May 2017***

NASA Unified-WRF (NU-WRF) model runs:
Slight improvement in simulated convective evolution



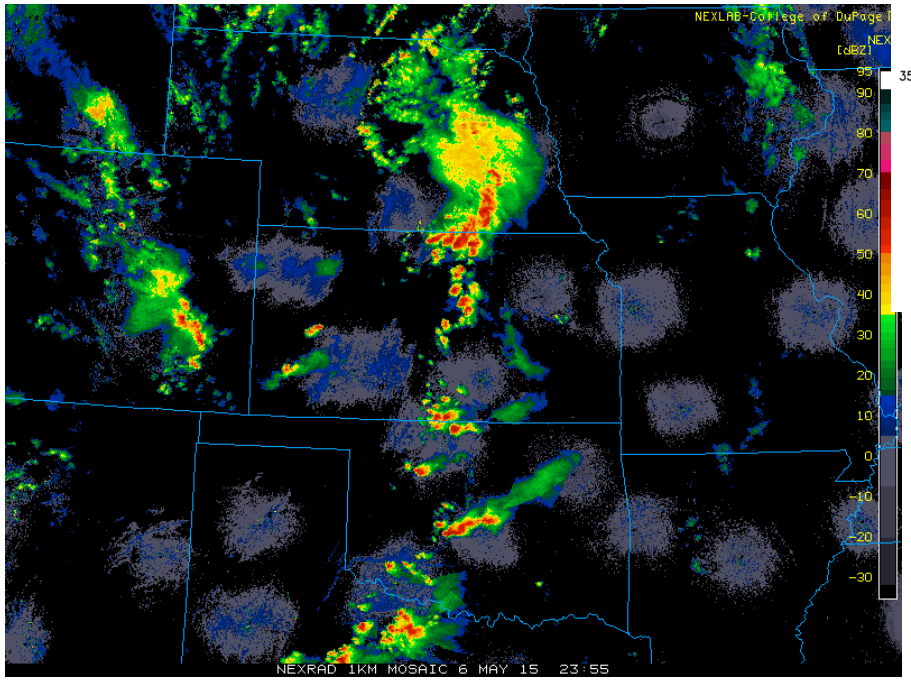
sportlis-initialized NU-WRF run

smapenhda-initialized NU-WRF runs more correctly retained convection in southern OK and northern TX into the overnight hours of 7 May 2015.



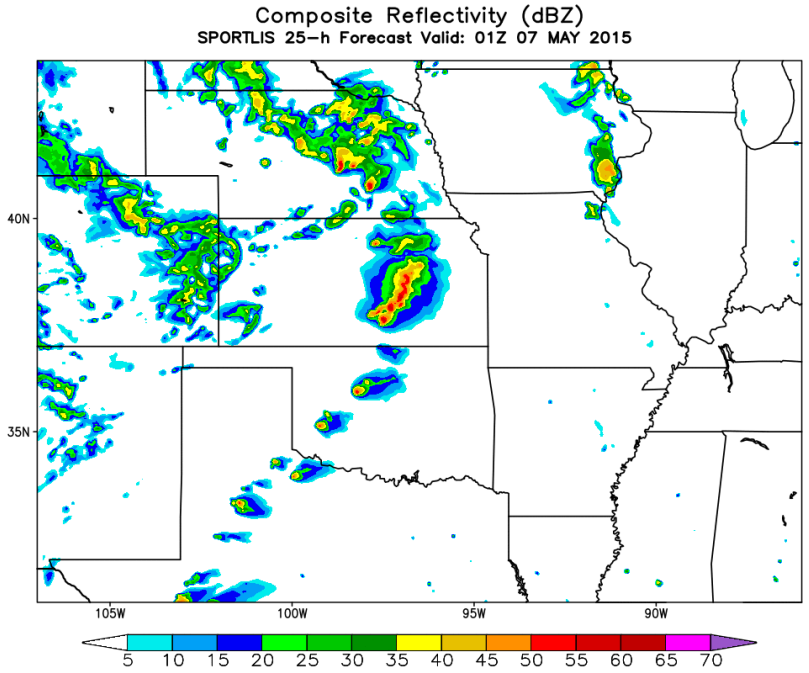
smapenhda-initialized NU-WRF run

24-hour NU-WRF forecasts and observed radar imagery valid at 0000 UTC 7 May 2015



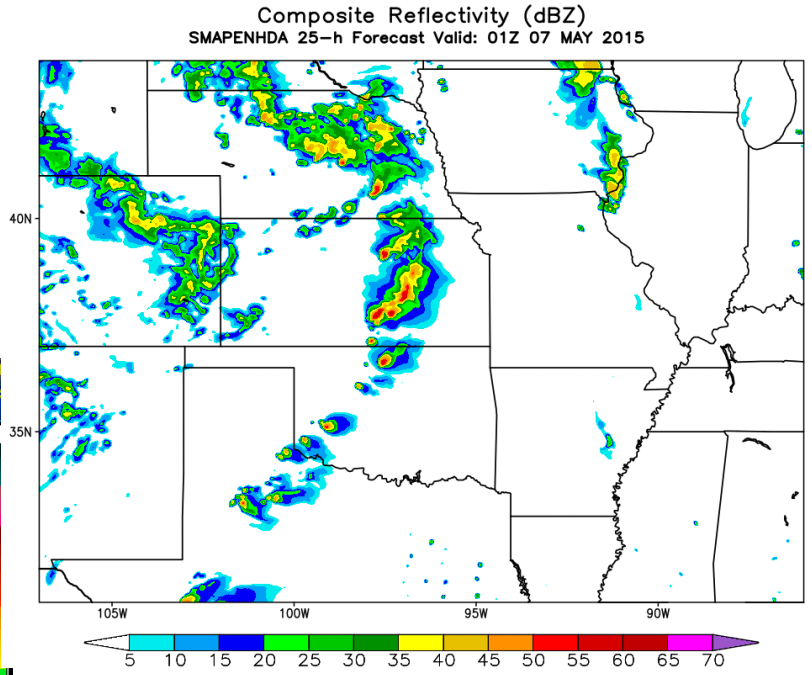
Observed regional radar reflectivity (dBZ)

NASA Unified-WRF (NU-WRF) model runs:
Slight improvement in simulated convective evolution



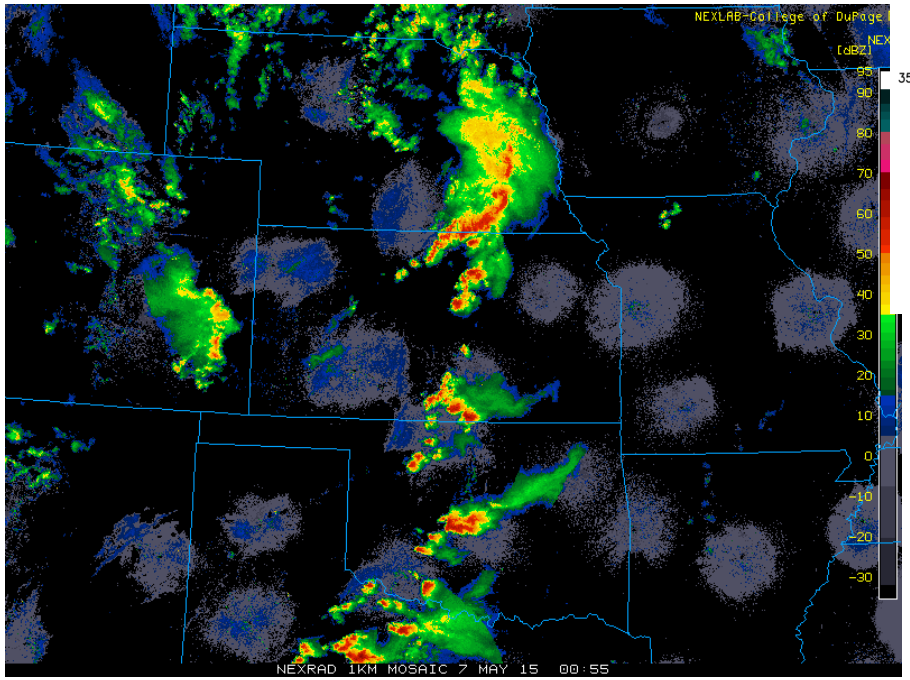
sportlis-initialized NU-WRF run

smapenhda-initialized NU-WRF runs more correctly retained convection in southern OK and northern TX into the overnight hours of 7 May 2015.



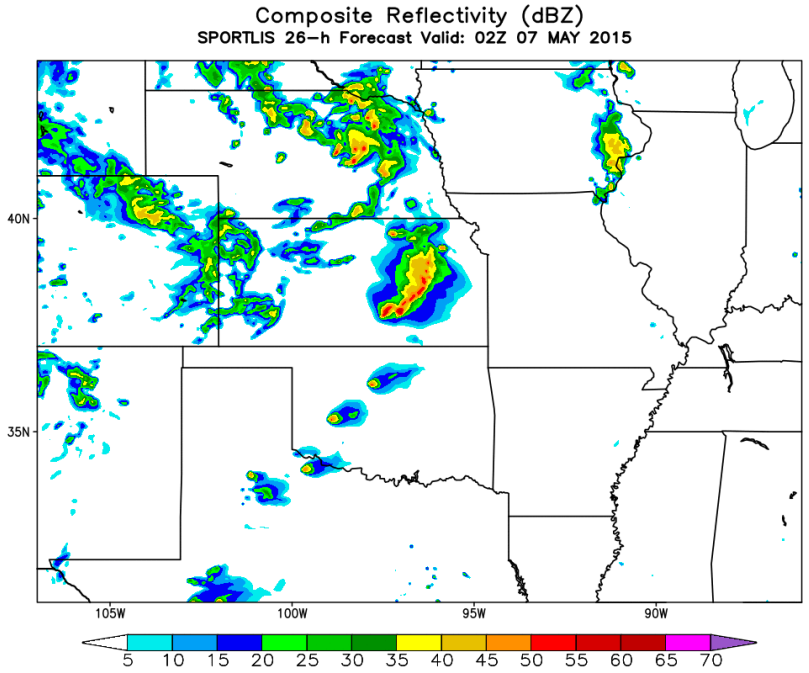
smapenhda-initialized NU-WRF run

25-hour NU-WRF forecasts and observed radar imagery valid at 0100 UTC 7 May 2015



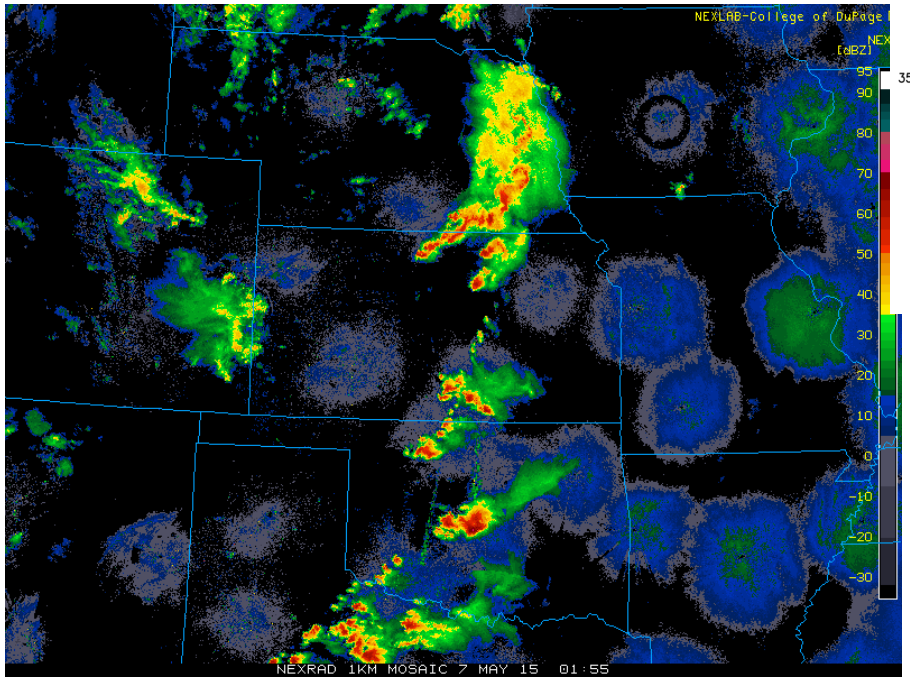
Observed regional radar reflectivity (dBZ)

NASA Unified-WRF (NU-WRF) model runs:
Slight improvement in simulated convective evolution

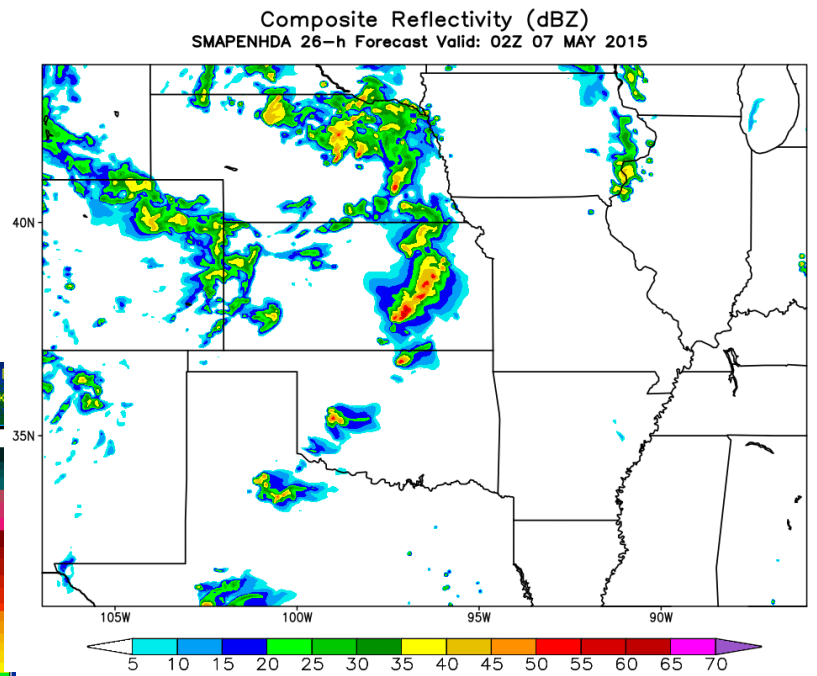


sportlis-initialized NU-WRF run

smapenhda-initialized NU-WRF runs more correctly retained convection in southern OK and northern TX into the overnight hours of 7 May 2015.



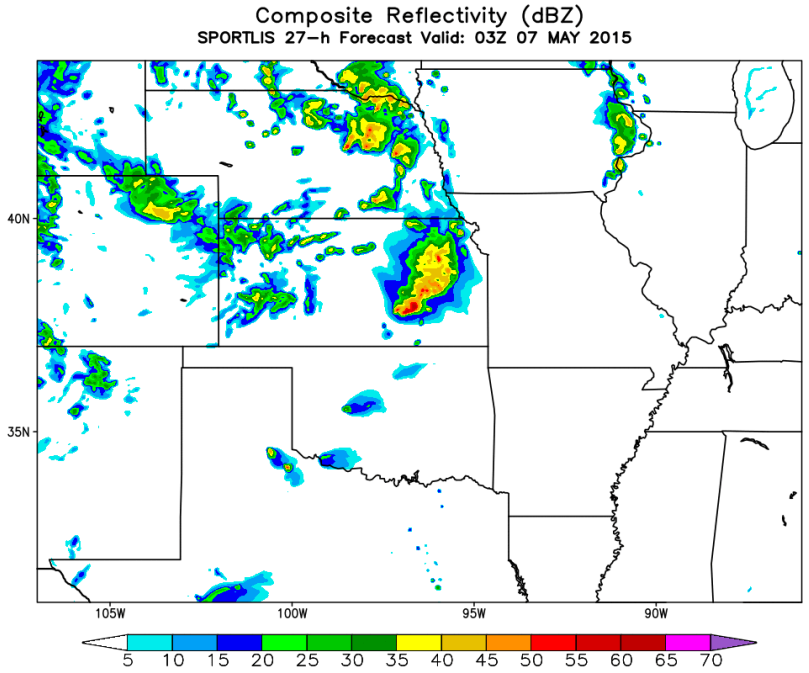
Observed regional radar reflectivity (dBZ)



smapenhda-initialized NU-WRF run

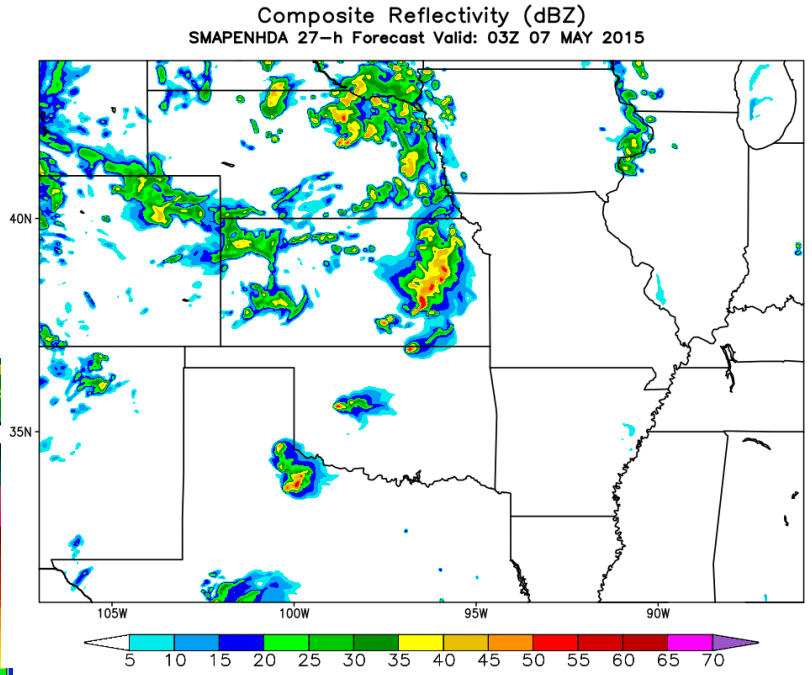
26-hour NU-WRF forecasts and observed radar imagery valid at 0200 UTC 7 May 2015

NASA Unified-WRF (NU-WRF) model runs:
Slight improvement in simulated convective evolution



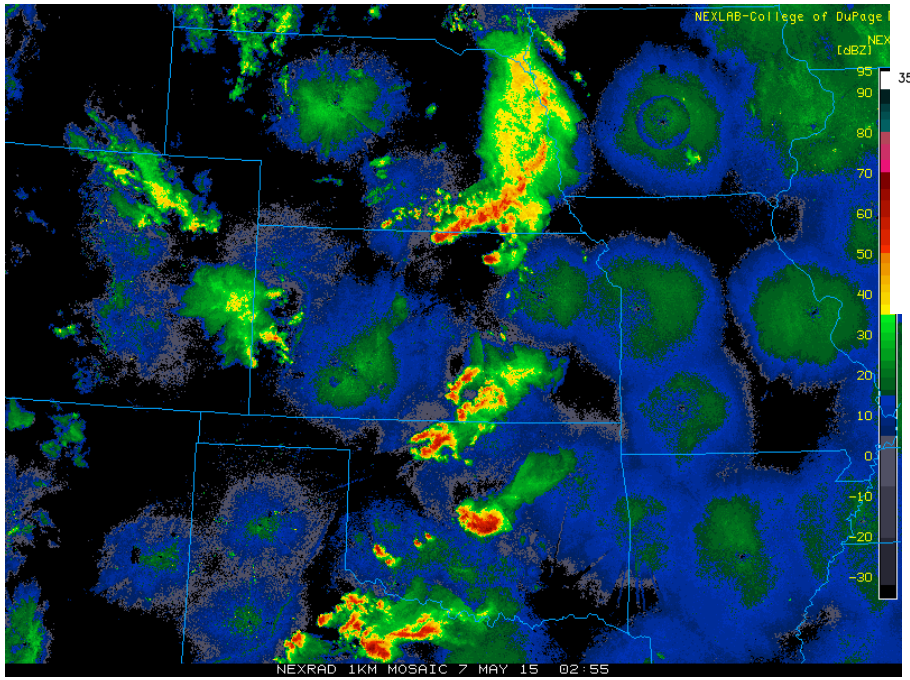
sportlis-initialized NU-WRF run

smapenhda-initialized NU-WRF runs more correctly retained convection in southern OK and northern TX into the overnight hours of 7 May 2015.



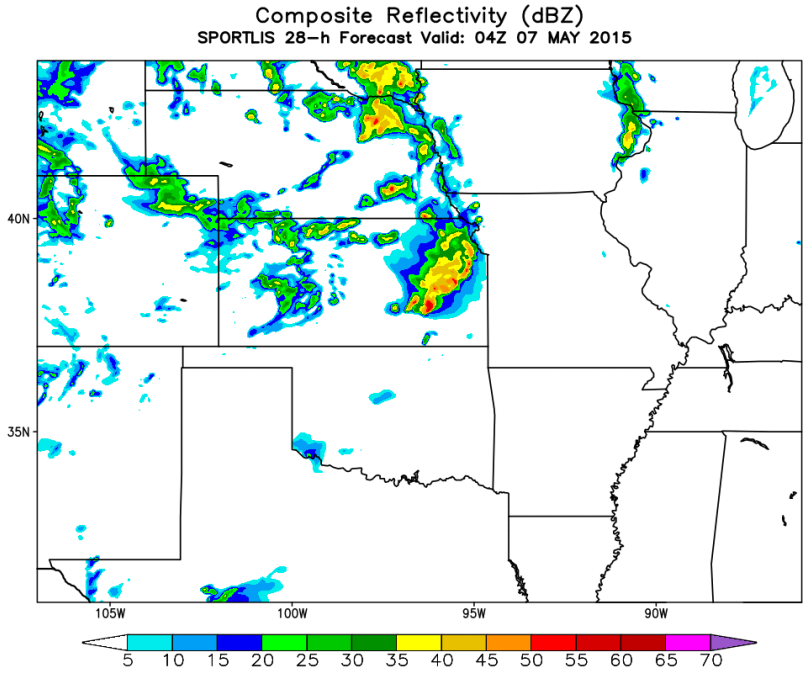
smapenhda-initialized NU-WRF run

27-hour NU-WRF forecasts and observed radar imagery valid at 0300 UTC 7 May 2015



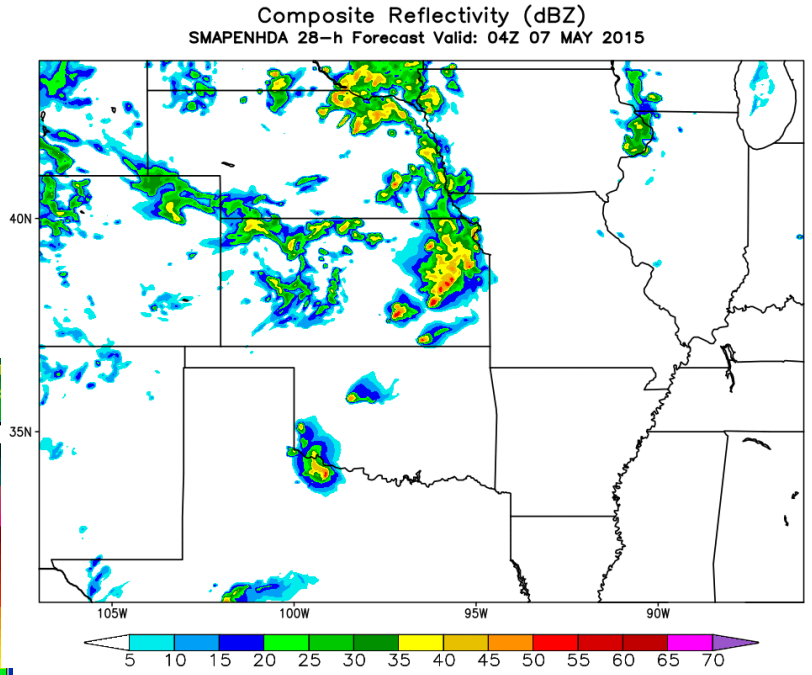
Observed regional radar reflectivity (dBZ)

NASA Unified-WRF (NU-WRF) model runs:
Slight improvement in simulated convective evolution



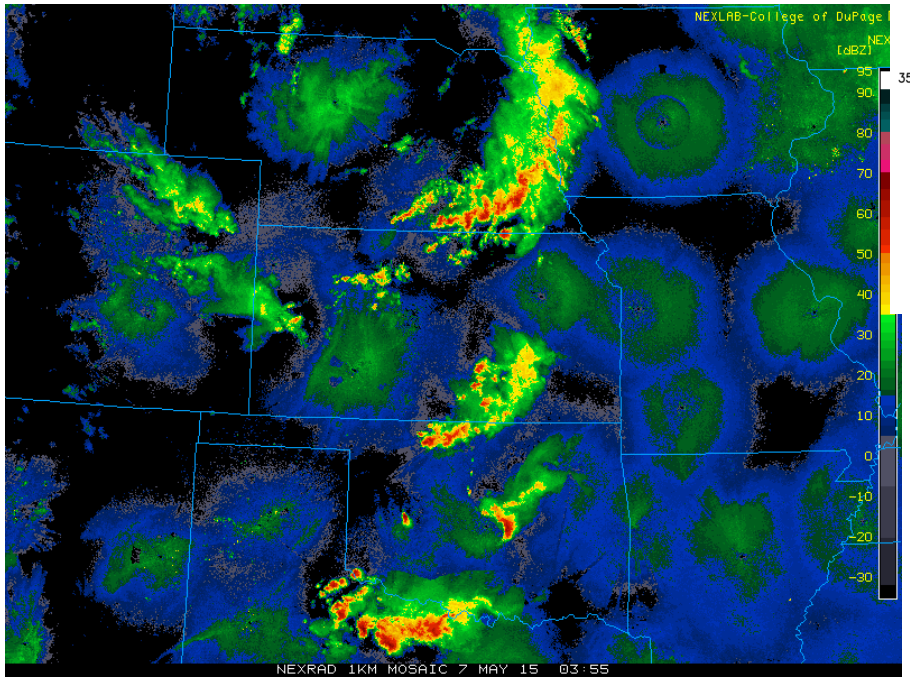
sportlis-initialized NU-WRF run

smapenhda-initialized NU-WRF runs more correctly retained convection in southern OK and northern TX into the overnight hours of 7 May 2015.



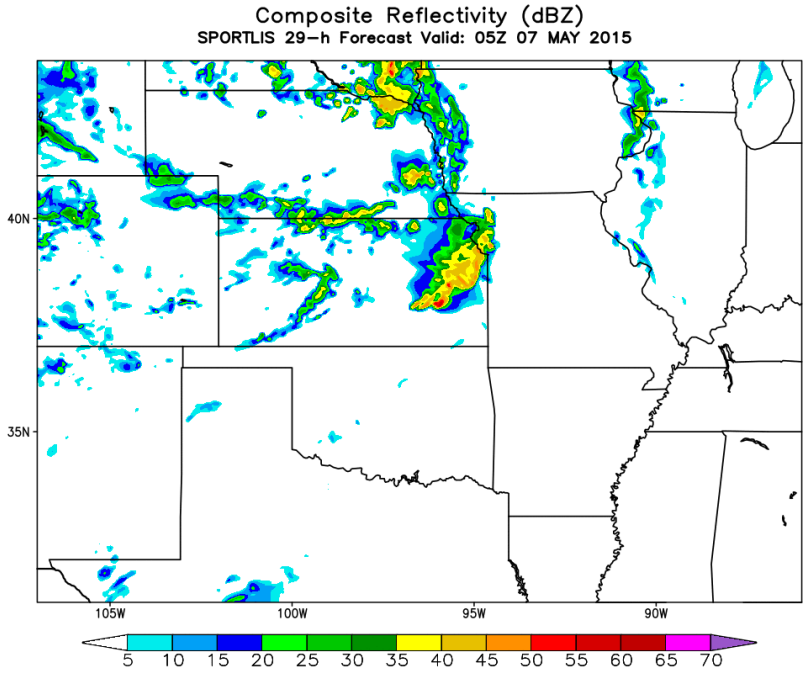
smapenhda-initialized NU-WRF run

28-hour NU-WRF forecasts and observed radar imagery valid at 0400 UTC 7 May 2015



Observed regional radar reflectivity (dBZ)

NASA Unified-WRF (NU-WRF) model runs:
Slight improvement in simulated convective evolution



sportlis-initialized NU-WRF run

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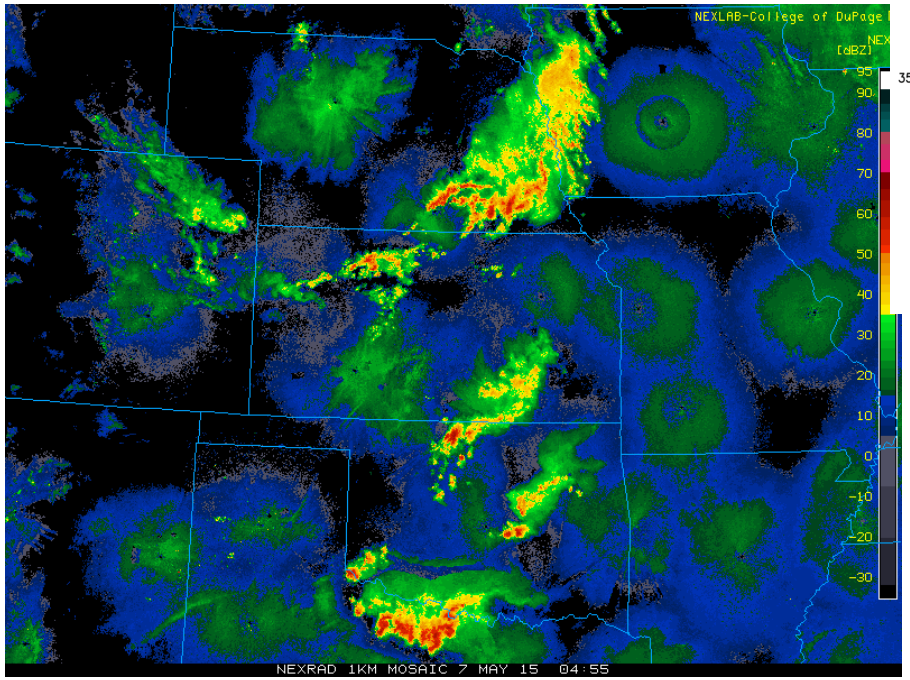
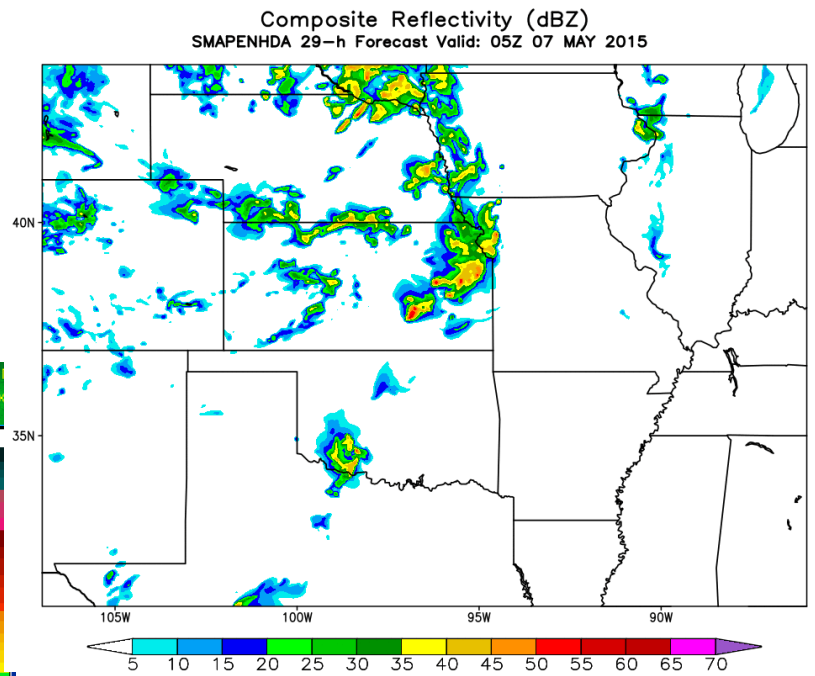


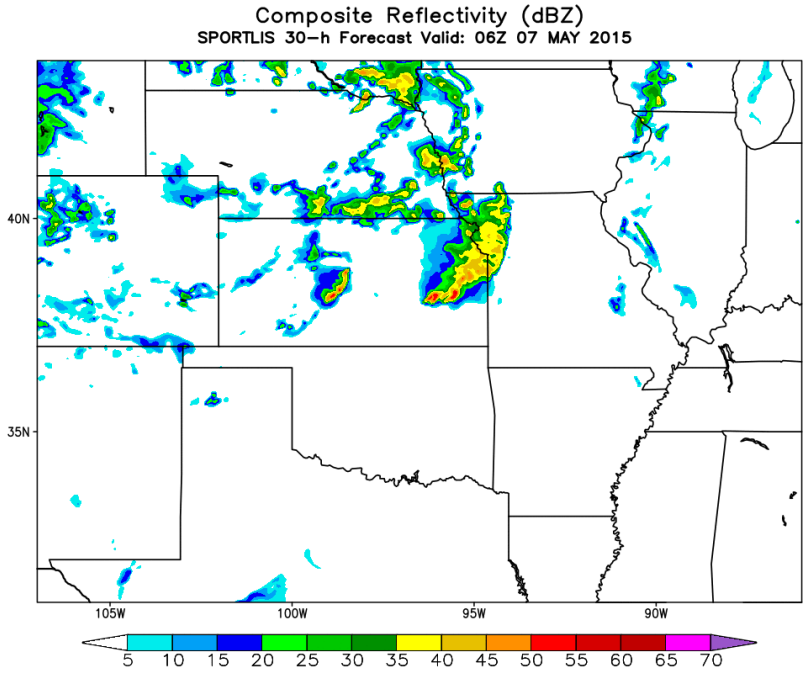
Observed regional radar reflectivity (dBZ)



smapenhda-initialized NU-WRF run

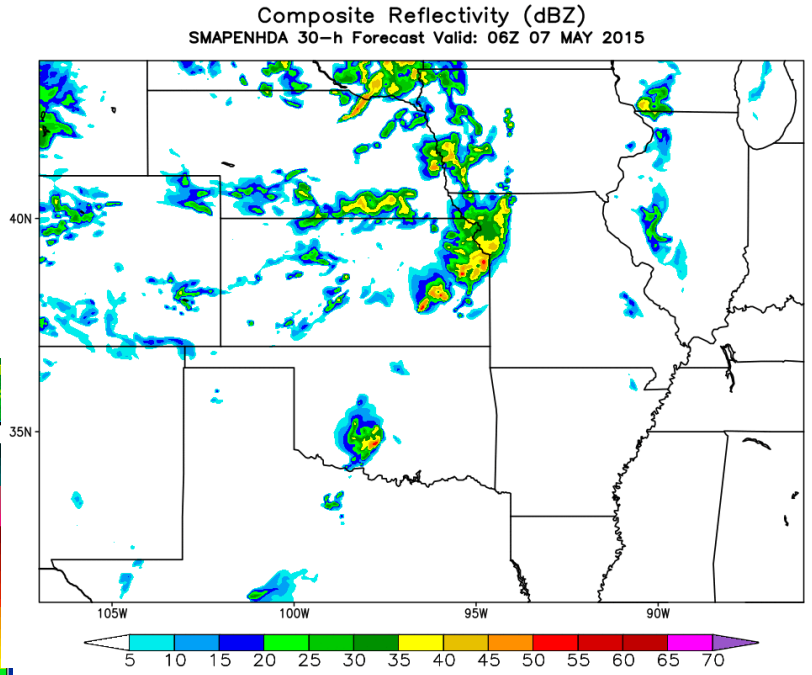
29-hour NU-WRF forecasts and observed radar imagery valid at 0500 UTC 7 May 2015

NASA Unified-WRF (NU-WRF) model runs:
Slight improvement in simulated convective evolution



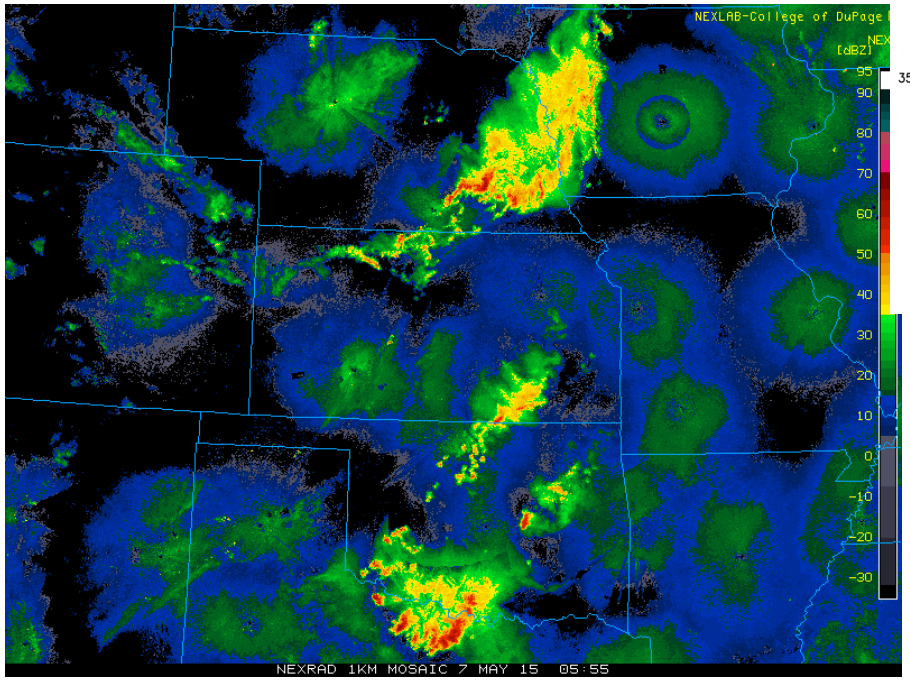
sportlis-initialized NU-WRF run

smapenhda-initialized NU-WRF runs more correctly retained convection in southern OK and northern TX into the overnight hours of 7 May 2015.



smapenhda-initialized NU-WRF run

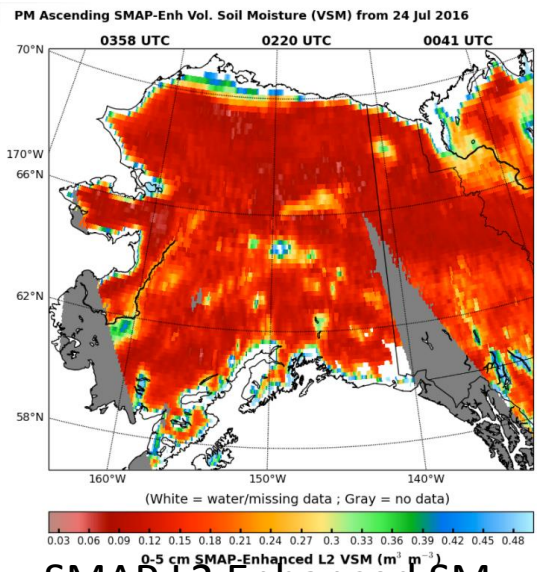
30-hour NU-WRF forecasts and observed radar imagery valid at 0600 UTC 7 May 2015



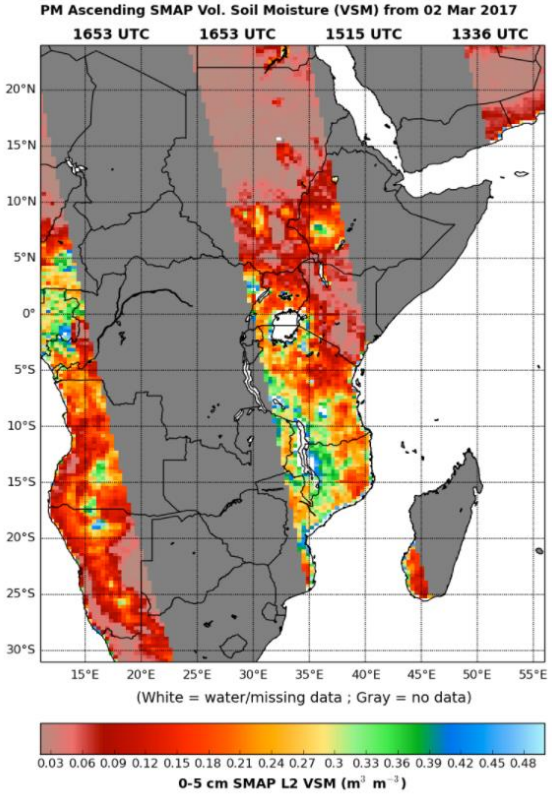
Observed regional radar reflectivity (dBZ)

Future Plans

- Soil Moisture
  - Refine methodology (layers, bias corrections)
  - Validation of soil moisture against stations
- NWP Initialization
  - Validation of 48-hr NWP forecasts
    - High-impact case studies
    - Comprehensive seasonal validation
- Africa domain
    - Limited ground validation data
    - Focus on NWP
- Alaska domain (wildfire threat)



SMAP L2 Enhanced SM



Acknowledgments

- Land Information System Team (NASA-GSFC)
- SMAP Science Team and Early Adopters Team
- Steven Quiring, Texas A&M University (now @Ohio State U.)
- Brent McRoberts, Texas A&M University
- Funding: NASA Earth Science Division
  (ROSES 2015 Science Utilization of SMAP Mission Program)

Questions and Comments?

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